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INDEX TO ADVERTISERS

	PAGE
Ajax Electric Furnace Corp.	iii
Almo Radio Co.	ix
Arrow Tool, Die and Machine Co., Inc.	ix
Atlas Photo Engraving Co.	xii
Bell Telephone Laboratories	vi
Bolger-Parker Co.	xii
Buten, M., & Sons	xi
Coleman, W. B., & Co.	iv
Damon & Foster	iv
Davidson, P. L.	iv
Eggly-Furlow Engineers	iv
Fehr & Johnson, Inc.	xii
Fidelity-Philadelphia Trust Co.	viii
FRANKLIN INSTITUTE, Awards	xiv
FRANKLIN INSTITUTE, Laboratories	Fourth cover page
FRANKLIN INSTITUTE, Membership	Third cover page
FRANKLIN INSTITUTE, Planetarium	xiii
Harris-Dechant Associates	iv
Herbach & Rademan	xii
Hess & Barker	xi
Kearney Lumber Co.	xii
Lancaster Press, Inc.	x
Leeds & Northrup Co.	Second cover page
Leopold, Charles S.	iv
Levy, Max & Co.	ix
Philco	ii
Shanahan & Co.	xii
Steinberg, Albert, and Company	xi
Thomas, Arthur H., Co.	ix
Yarnall-Waring Co.	x

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CONTENTS

Wind Tunnels—Why and Where ..... C. A. SCARLOTT 257

Upward Stepped Leaders from the Empire State Building ..... B. F. J. SCHONLAND AND D. J. MALAN 271

A Determination of μ-Mesotron Rest Lifetime and a Verification of the Relativistic Expression for Variation of Lifetime with Momentum ..... D. W. SEYMOUR AND W. F. G. SWANN 277

A String-Net Analog for the Numerical Solution of the Equations of Laplace and Poisson ..... PETER L. TEA 287

Notes from the National Bureau of Standards 305

The Franklin Institute
- Library 311
- Journal of The Franklin Institute 313
- Membership 314
- Notes from The Franklin Institute Museum 315
- Notes from the Biochemical Research Foundation 317
- Notes from The Franklin Institute Laboratories for Research and Development 319

Book Reviews 320

Book Notes 326

Current Topics 276, 304, 328

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WIND TUNNELS—WHY AND WHERE

BY

C. A. SCARLOTT [1]

EDITORIAL INTRODUCTION

The wind tunnel is the foundation of every vehicle of flight. This has been so to date; it will become more so in the future. The rapid rise in speed of airplanes, the crossing of the sonic barrier, new types of power plants, rockets, and guided missiles have created a mass of complex, interrelated problems far beyond any prospect of solution via known data. This has led to a vast specialization of wind tunnels and a great spread in numbers, physical locations, sizes, air speeds, operating conditions, and functions.

An airplane—even an old DC-3—is deceptively sleek in appearance. The wings must, to be sure, be of the right section and placed at the right angle—aircraft men call it angle of attack—to get the maximum lift. But the fuselage, the engine cowlings, the juncture of wings and body are nicely smoothed out. All surface contours are well rounded to permit smooth flow of air around them. Even the high-speed planes have the obvious (it seems) needle-like nose and well-tapered bodies to meet the high-speed air streams with least resistance.

What, then, all this business about more and bigger wind tunnels? What more can be done? The little black books of the aerodynamicists surely must be filled with air-flow data for every conceivable shape of plane and part and for all speeds up into the sonic.

The answer from all those who build engines, airplane air-stream components, and airframe builders is a resounding "no," loudly echoed by those who are working on the frontiers of rockets and guided missiles. Until now, they insist, the problems requiring wind-tunnel solution have been accumulating faster than existing tunnel facilities can provide answers. Furthermore, for certain categories of problems that must be

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(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors in the JOURNAL.)

solved before supersonic flight can become common, all the necessary tunnels don't yet exist—although they are on the way.

Flight is becoming more complex by the minute. Most of the new problems rise out of the fact that as air speeds go up aerodynamicists are more and more tangling with old man Mach number. Mach one is the speed of sound. It is simply a fundamental manifestation of the rate at which pressures or disturbances are transmitted through the atmosphere in question. The rate at which a pressure wave travels through air, that is, what animals recognize as sound, varies with its temperature. Specifically it is proportional to the square root of the absolute temperature. At 60° F., this rate is about 760 mph.; at zero it is 718; and at −67° F. it is 663. And this is how altitude gets into the act, because altitude, per se, hasn't anything to do with Mach number. It is only because the higher the altitude the colder the air. (Between 35,000 ft. and about 100,000 ft., temperature is pretty generally constant at between −65° and −70° F.)

MACH NUMBER

At speeds less than sonic, that is, Mach numbers smaller than unity, the pressure wave moves out in advance of the object causing the air molecules to begin to evade so that they flow readily around the object when it does arrive. They have a chance to make room in an orderly fashion for the visitor. At Mach 1 or faster, that is, with the object moving at the same rate as, or faster than, the pressure wave moves, there is no advance preparation of air molecules for smooth flow. They have no chance to get out of the way. They are struck "broadside." The result is shock, which manifests itself on an airplane as a sudden large increase in drag and loss of lift.

One trouble is, however, that this sonic regime is not a sharply narrow speed through which a vehicle can quickly pass—even though violently—to reach the supersonic region where conditions are more stable, somewhat as they are in subsonic flight, but where the cost in propulsive power is terrific. The transition from subsonic to supersonic is a band or zone of speeds. The local rates of air flow about an airplane differ. The air may be moving over some surfaces at Mach one, while over others it is still less than one. The tips of propellers were the first of aircraft components to get into compressibility-effect difficulty. Thus compressibility effects must be considered in aircraft design for flight speeds of less than sonic. This has brought into being a zone of speeds called the transonic, commonly considered as Mach 0.7 to 1.3.

Likewise air apeeds of Mach 1.3 up to about Mach 5 (an arbitrary number) are labeled supersonic, and above Mach 5, the term hypersonic is applied.

It is the transonic and low supersonic regions that today occupy the attention of aircraft people and are the big news in the wind-tunnel

field. But that does not make the subsonic test facilities obsolete. An airplane can be designed to fly efficiently at supersonic speeds, but it also must be able to land. Thus in take-off and landing it must also fly at subsonic speeds and to reach top speed must pass through the transonic range. Thin, swept-back wings of small area present many problems in subsonic operation, for which answers can come only via tunnel testing. The countless possible shapes, areas, angle of sweep, and other variables must be explored for their slow-speed performance. Large old tunnels, which produce winds of around 200 mph. and were once considered fast, are kept busy on landing and take-off problems that accrue from the new wing and fuselage shapes needed for supersonic flight.

Jet engines have compounded the testing needs. The shape, size, location of air inlets, internal ducts, and exhausts must be explored in infinite detail if maximum use of the available energy is to be made—and in high-speed flight no energy can be wasted.

Adding to the complexity, a small change in jet-engine air intake made to improve engine thrust can disrupt adversely the air flow around certain wing areas or control surfaces. These must be explored and compromises effected. And so on it goes, seemingly without end.

High-speed flight brings with it new problems and greatly intensifies others that can be ignored or easily met in subsonic flight. Flutter, for example. Higher speed and thinner structural sections used at those speeds cause flutter—which is what a flag does in the wind or a venetian blind will sometimes do in a draft. To show how complex some of these aerodynamic problems become, consider that the problem of flutter of, say, a wing section differs whether the wing fuel tank is full, partially full, or empty.

The behavior of control surfaces and of the airplane itself in gusts becomes more critical at higher speeds.

Icing of wing surfaces, controls, jet-engine ducts can happen more quickly and can be more disastrous with the faster airplanes. All this must be looked into in tunnels.

REYNOLDS NUMBER

Mach number is not the only factor that commands continued obeisance from wind tunnelers. Another is Reynolds number. It is the one that has to do with scale effect. Numerically it is the product of three numbers—air density, relative speed, and length of object, divided by a fourth, the viscosity of the air. These numbers with actual aircraft come large. The Reynolds number for a B29 over its normal speed range is 13 to 28 million; for a Thunderbolt fighter plane it is 5 to 20 million. Reynolds number has no quality connotation. The significance of Reynolds number lies in the fact that it expresses the ratio of the pressure forces to the viscous forces for any given flight condition.

Reynolds number is important in any model testing because the closer the full-scale value can be approached in the test chamber, the closer is the test to reality and the less the need for extrapolation.

Since large wind-tunnel test sections and high air speeds simply do not go together, it is possible to test in a wind tunnel an actual airplane or even a sizable section of one at full Reynolds number only at low speed. Because tunnel test sections are of limited size, scale models must generally be used. The equation shows that Reynolds number can be kept high by increasing the air density. For this reason many tunnels are pumped up to higher pressures. For example, Langley has five pressure tunnels. One is a 19-ft. round test section that can be operated at speeds up to 260 mph. and 2.3 atmospheres of pressure, and a smaller one with a 3 by $7\frac{1}{2}$-ft. section in which tests can be run at air speeds of 350 mph. and densities of 10 atmospheres. Another is the 4 by 4-ft. supersonic tunnel. The fifth is the 8-ft. transonic pressure tunnel.

On the other hand, it is sometimes desired, as with engine components, to make tests under air conditions equivalent to high altitude. Hence some tunnels can be operated under partial vacuum. Lewis Flight Propulsion Laboratory, Cleveland, has such a 500-mph. high-altitude tunnel. The Wright Field 10-ft. round transonic tunnel can be operated over the range of air densities of 0.12 to 2 atmospheres.

TUNNEL VARIETIES

Various expedients are used to achieve high Mach numbers with a limited power input. One is the intermittent or blow-down tunnel. In one type the air is pumped up to high pressure and stored in a large reservoir. When a test is to be made a quick-acting valve is opened to allow the stored air to rush through the test section at high velocity. In another type a large chamber is evacuated and the air, during the test, is drawn through the test section into it. Sometimes a pressure tank is used on one side and a vacuum chamber on the other. One of these is being erected by the Air Force at the Arnold Engineering Development Center at Tullahoma, Tenn. One exists at Langley Aeronautical Laboratory operating in the speed range of Mach 7 to 10. A blow-down tunnel uses less motor horsepower but the time available for a test run is but a few seconds or perhaps a minute or two.

Another way to get a high Mach number without paying the full price of motor horsepower is to change the speed of sound. In Freon 12, because of its greater molecular weight the speed of sound is but 40 per cent that in air. Thus in a tunnel circuit containing a Freon atmosphere, Mach one is achieved at 300 mph. instead of 750. Likewise, because density is a factor in the Reynolds equation, use of Freon improves the scale number by a factor of 3.6. Freon, however, introduces complexities of mechanical structure and of data resolution. As a con-

sequence Freon is used in only a few installations operating in the high subsonic or transonic speed ranges. They are especially useful in studying problems of aeroelasticity such as flutter.

The terms subsonic, transonic, supersonic, and hypersonic are more than just casually useful categories for air speeds. They refer as well to basically different types of wind tunnels. Ordinarily in no practical tunnel can all test conditions be obtained although it could be done with interchangeable test sections.

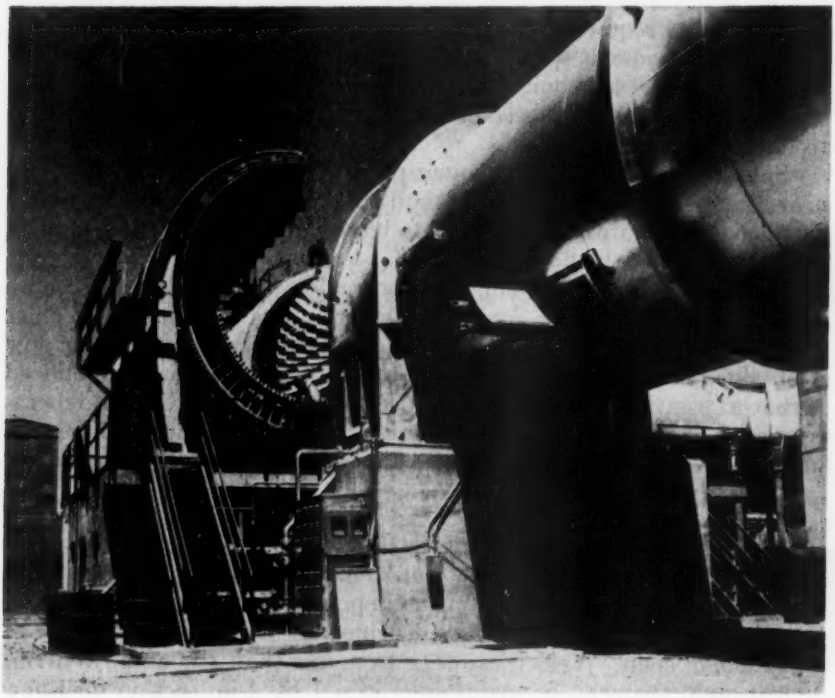

FIG. 1. NACA's 6 by 6-ft. supersonic wind tunnel at Ames Aeronautical Laboratory, Moffett Field, California. The compressor is shown with its stator opened to permit inspection and maintenance. In operation, two 25,000-hp. motors drive the compressor creating air speeds from 840 to 1500 miles per hour.

This comes about because of the way air behaves at these three conditions. In a subsonic tunnel, the test section is reduced in area compared with the remainder of the tunnel. Air rushing through this restriction speeds up. The greater the restriction or the more horsepower put into the fan the faster the air whistles through the narrowed test zone—up to Mach 1, that is. When the speed of sound is reached no amount of increase in fan power will increase the air speed at the throat or test section. All the additional power goes into shock losses, that is, heat. This is called the choking effect and is the reason why the

transonic tunnel is a special problem that has taken so long to solve. In effect, it is because the molecules have become so crowded that they cannot get out of each other's way at a speed above sonic.

Supersonic air speeds can be obtained only in a tunnel that first converges and then diverges, the supersonic speeds occurring in the expanded section—not the smaller section. The air molecules reach sonic velocity—but no more—in the constricted zone, whereupon on reaching the region of expanding cross section they now accelerate—and do so at a rate faster than the flow behind them. Given the minimum pressure required to reach sonic speed in the first and narrower throat, the supersonic speed depends only on the expansion rates of the divergence. A supersonic tunnel, therefore, must normally have a separate nozzle for each speed or else an adjustable one of precisely controllable shape.

Subsonic and supersonic tunnels present special operating problems near Mach 1. Between Mach 0.9 and 1.2 either tunnel is so sensitive to small changes in area that a model to be tested, or even disturbances in the tunnel, upset the flow stability.

A solution to this problem of transonic flow was developed at Langley. For it John Stack, Assistant Director, was awarded the Collier Trophy by the President in 1952. The manner in which transonic flow is obtained is still classified information. All that has been announced is that a "ventilated throat is used." Engineers at the Cornell laboratory have likewise developed a solution in which the principal difference has to do with the openings and the manner of return of the bled air.

THE COMPOSITION OF THE WIND-TUNNEL INDUSTRY

There are about 200 wind tunnels in the United States. They range in size of test section from a few square inches to the 40 by 80-ft. giant at Ames Laboratory in California and in power from $1\frac{1}{2}$ hp. up to 216,000 hp., not yet completed for Arnold Engineering Development Center at Tullahoma, Tenn. Velocities range from less than 100 mph. to about 10,000 mph. that can be maintained in a 1 by 4-in. section for a few milliseconds at the Cornell Aeronautical Laboratory at Buffalo.

The wind tunnels of the country divide into several classes of ownership: those owned by universities—or manufacturer-owned, university-operated; private engine and airframe builders; government agencies, particularly the Armed Forces, the Arnold Engineering Development Center under ownership and direction of U. S. Air Force and contractor-operated; and the National Advisory Committee for Aeronautics.

University Tunnels

Some 17 of the nation's universities have about 30 wind tunnels, almost evenly divided between subsonic and supersonic, with but one transonic. These subsonic tunnels have test sections as large as 12 ft.,

with air speeds generally in the 125- to 300-mph. class and with drive horsepowers of 250 to about 2500 hp. The scholastic supersonic tunnels have sections as little as 1 by 4 in. and as much as 17 by 20 in., with a span of Mach numbers from 1.3 to about 5.

University tunnels serve two important functions. The basic one, of course, is classroom instruction. It is from schools so equipped that come the aerodynamically trained men essential to research and testing in the larger laboratories in government and in industry.

Also, important research work is done in university wind tunnels. Much of this is of a fundamental nature, with some undertaken by the schools themselves, and some of it on contract for the Air Force, Navy, NACA or for private companies. Also, schools work on specific component problems for government or industry on a contract basis.

Privately-Owned Tunnels

Most airframe and engine builders have at least one tunnel. Generally these are subsonic tunnels, with test sections up to 10 or 12 ft. The outstanding example of a privately owned facility is the Edmund T. Allen Memorial Laboratory of the Boeing Airplane Company laboratory at Seattle. Their original tunnel was built in 1944 and was powered by an 18,000-hp. synchronous motor and eddy-current clutch. It has recently undergone extensive reconstruction consisting, in part, of the addition of a 36,000-hp. induction motor making 54,000 hp. in all, and changes in the 8 by 12-ft. test section. Speeds up to Mach 1.2 have been attained. This is the world's largest transonic tunnel owned and operated by a private company.

In one case several aircraft companies have combined resources to provide a cooperative facility that is larger and more flexible than any one could afford. This is the Southern California Cooperative Wind Tunnel operated for the sponsoring companies by the California Institute of Technology at Pasadena.

Another outstanding research facility is the Cornell Aeronautical Laboratory located near Buffalo. Although owned by Cornell University and administered by it, the laboratory's function in the educational program is secondary. It is a non-profit research institution engaged primarily in work on a contract basis for government and military agencies and private companies with the "profits" from such devoted to the solution of basic problems primarily in the field of flight. The Cornell laboratory has an $8\frac{1}{2}$ by 12-ft. variable-density wind tunnel for operation throughout the subsonic range. The test section has been modified so that it can, at will, be fitted with a 3 by 4-ft. transonic test section of a type developed by Cornell engineers and capable of operation over the Mach number range from 0.9 to 1.3. Also it is provided with a propeller dynamometer that makes it possible to apply 2000 hp. to a propeller while operating the tunnel over the transonic range.

The advantage in flexibility and saving in time to manufacturers of having tunnel facilities in their own backyard, or even in a nearby co-operative center, are obviously great. But, because wind tunnels come high in cost, there is a limit to how much of this can be done—a limit becoming increasingly severe with the growing and doubly difficult need for tunnels of higher Mach numbers and larger test sections.

Government-Owned Tunnels

In addition to the NACA, which we'll return to in a moment, several other branches of the government operate wind tunnels. The Bureau of Standards has two small subsonic tunnels. The Navy has about 15, the largest being a 27,000-hp. transonic tunnel at Carderock, Maryland. The Bureau of Ordnance of the Army at Aberdeen, Maryland has two supersonic tunnels of 13,000 hp. each.

Aside from those of NACA the largest existing wind-tunnel center is one operated by the Air Force at the Wright Air Development Center near Dayton, Ohio. Located there are three subsonic tunnels. Two are small ones, but the third has a 20-ft. circular test section and the relatively high subsonic air velocity of 425 mph. This tunnel, built in 1941, is powered by a 40,000-hp. motor, which, for ten years, was the largest induction motor in the world. Since the war a very small transonic and one 10-ft. transonic tunnel with a 40,000-hp. drive have been added at WADC. Also a 5000-hp., 2 by 2-ft. supersonic and a 1000-hp. 6 by 6 in. supersonic tunnel have been recently built at Wright Field.

While the wind-tunnel facility at Wright Field is sizable, it does not compare with what the Air Forces are building at Tullahoma, Tenn. There, on a large tract of Tennessee "barrens," facilities are being erected for aerodynamic testing on an unparalleled scale. Called the Arnold Engineering Development Center, it is a part (as are Wright Field Laboratories) of the Air Research and Development Command of the U. S. Air Forces, with headquarters in Baltimore.

The Tullahoma plant at the outset will be comprised of three units. The Engine Test Facility will have three test chambers and a test bed in which it will be possible to carry out research, development, and evaluation programs on turbojet, turbo-prop, and small ram-jet engines under simulated flight conditions and altitudes up to about 80,000 ft. Temperatures as low as $-120°$ F. will be reached. Approximately 75,000 hp. are required to operate the compressor and exhauster system. An adjunct to this facility is being constructed in which the largest ram-jet engines now under development can be tested. Much of the equipment in the Engine Test Facility was found operating in Germany during the war and was brought over to this country as reparations. This facility is undergoing its shakedown and calibration runs.

Second of the three major AEDC plants is the Gas Dynamics Facility. It will consist of a group of supersonic wind tunnels for de-

velopmental testing of models of aircraft, projectiles, and missiles designed to operate at extremely high speeds; some of these tunnels are to operate in the hypersonic range. The primary air mover is an extremely versatile compressor plant containing six axial compressors and six centrifugal compressors, driven by electric motors totaling almost 100,000 hp. One of the smaller supersonic tunnels has been in operation for several months.

The third and largest operation—largest anywhere in fact—will be the Propulsion Wind Tunnel. It will consist of a transonic and a supersonic tunnel, each with a test section 16 ft. square. They are intended for developmental testing of full-scale operating ram-jet and turbo-jet power plants installed in missiles or aircraft. In addition, propellers and aerodynamic models can be tested. The two tunnels will be arranged side by side so that both can be served by one power plant of 216,000 hp. It is significant of the thinking for the future that space is left for the addition of a 180,000-hp. motor to the present four, making available about 400,000 hp. to either tunnel.

The NACA

By all odds, the outstanding factor in the wind-tunnel business has been and is the NACA. This important body was established by Congress in 1915 as an agency reporting to the President. While the bulk of its work is obviously of interest first to military aviation it is not a part of the Armed Forces. As its name states it is run by a committee—a board of directors would be more descriptive. These 17 men, who serve without pay, are members of the top echelons of science, industry, the Armed Forces and other government agencies. They are appointed by the President.

The wind-tunnel activities of NACA (it engages in other aspects of aircraft and guided-missile research) are located at three centers: Langley Aeronautical Laboratory, near Hampton, Virginia; Ames Aeronautical Laboratory at Moffett Field, near San Francisco; and Lewis Flight Propulsion Laboratory, close to Cleveland. Langley is the oldest. Also it is the largest both in number and variety of facilities. The first tunnel was built there in 1919. It was a 5-ft. tunnel capable of only a 100-mph. breeze. Since then many specialized tunnels have been erected and new ones are currently being added or rebuilt. Today it resembles the campus of a large university, spread out over several hundred acres of ground that is part of Langley Field. Its buildings house some 20 different wind tunnels. Many are small, special-purpose tunnels, such as for studies of free-flight models for spin. Largest is the "full-scale" 30 by 60-ft. tunnel where an 8000-hp. motor provides air speeds up to 120 mph. Five supersonic and four transonic tunnels are in operation or under construction. Tops for speed is one capable

of Mach numbers up to 10 in a test section one foot square. Powerwise, Langley's largest are two with 60,000-hp. drives.

In 1940, NACA established a new center of operations at Moffett Field in California. This is Ames Aeronatuical Laboratory, which is now equipped with some nine tunnels particularly suited to high-speed aerodynamics. The largest, physically, is the breathtaking full-scale tunnel with a test section of 40 by 80 ft., large enough to take most pursuit planes and several of the small bombers. The circuit of the air-passage is more than half a mile. Powered by six 6000-hp. motors, air

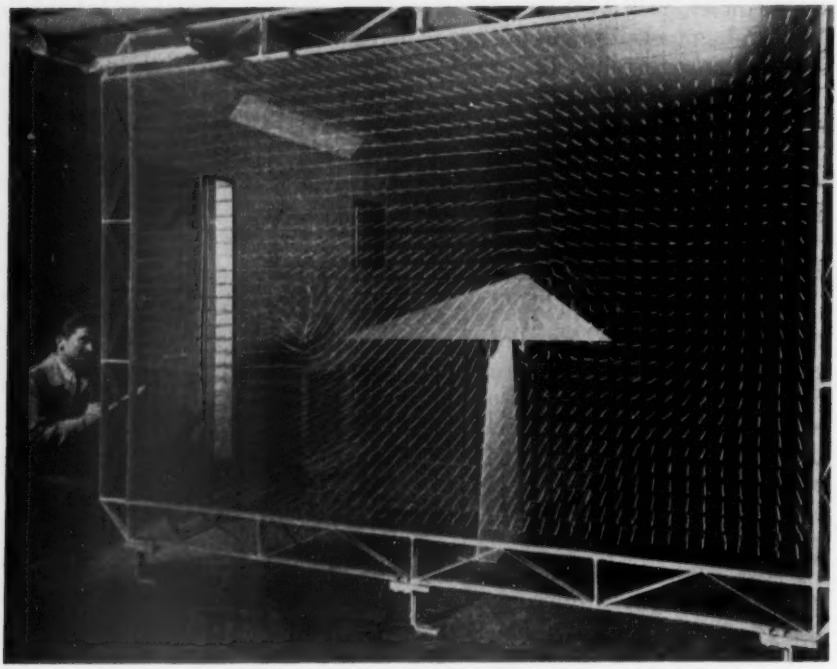

FIG. 2. A wire grid with white wool tufts, placed in the wake of a delta wing model in the NACA's 7 by 10-ft. wind tunnel at Langley Aeronautical Laboratory, provides a graphic picture of turbulence behind each wing tip. This tunnel is used largely for stability and control tests.

speeds in the test section reach 250 mph., very high for so large a test area. Also at Ames is the 6-ft. tunnel which is being repowered by a 110,000-hp. motor for transonic operation and a 180,000-hp. tunnel (216,000 hp. on a half-hour basis) being constructed with two throats. A 6 by 6-ft. supersonic tunnel has a 60,000-hp. drive. In addition to several smaller tunnels, Ames has four large tunnels with drives totaling 422,000 hp.

Only slightly younger than Ames is the Lewis Flight Propulsion Laboratory. The principal objective here is engine research. The

laboratory is now equipped with four supersonic tunnels, and other facilities. Its 6 by 8-ft. tunnel, capable of Mach number of 1.8 with a drive totaling 100,000 hp., is the largest supersonic tunnel now in operation anywhere. A new, larger supersonic tunnel is now under construction at Lewis.

INTERRELATIONSHIP OF TUNNEL OPERATION

With so many tunnels of different kinds and sizes operated by different groups, and remembering that wind tunnels are expensive masses of machinery, it is appropriate to ask about the coordination and integration of effort, and the extent of duplication of facilities. There is, indeed, considerable overlap in the abilities of different tunnels. But, let us quickly say, most of this duplication is entirely justified, if not downright essential. In the first place the amount of work to be done is so vast that many tunnels of one class are needed simply to provide the hours required to keep abreast of the load. This will be true as long as we are in an expanding air age—higher speed manned flight, larger aircraft, guided missiles, rockets, helicopters, new types of power plants, and so on. Until now, at least, the availability of tunnels has seriously lagged behind the need of them. The question at any wind-tunnel center has been, "which are the most urgent problems?" never, "what can we find to do?"

Also engine and airframe builders are scattered over wide areas of the United States. This makes a geographical spread of tunnels highly desirable.

There is no formal, integrating agency by which testing in institutional, industrial, and governmental tunnels is fully coordinated. While undoubtedly there has been some duplication of effort, there is much less of this than one might suppose. Certainly it has been small enough to be of no serious concern.

Actually there is an effective coordination on an informal basis. This is probably better. This ensues because of overlapping committees that direct the work in the government-owned tunnels and the fact that the results of all work done therein are available to those segments of industry entitled to have them. The NACA, just as its name implies, is a committee of high-level representatives of government, industry, and schools. One of its functions is that of coordinating aeronautical research in the United States. The reports of all unclassified work done become public information. Classified matter is available to all groups working in that area. The NACA group, by informal means, is kept well advised of work done in other laboratories, even to a large extent those of industry. To collect material for this article, the author visited many of the aerodynamic research and development centers of government and industry. We were impressed by the awareness in each group of what other groups are doing and the obvious desire among the aerodynamic-research fraternity to avoid unnecessary duplication of effort.

Beyond all this there is a general pattern of function that guides aerodynamic testing. The main endeavor of the NACA is research. Such is its stated primary assignment by Congress. However, even before World War II, NACA was always willing, when possible, to help do a bit of aerodynamic trouble shooting or assist the Armed Forces with a specific development problem. However, the bulk of its effort was directed to fundamental research. The fruits of those labors cannot be over-estimated. Much of the basic aerodynamic data in the design books used in industry came from NACA laboratories. Most of the

FIG. 3. The McDonnell Aircraft Company operates a transonic wind tunnel with a 7 by 10-ft. test section. Power is supplied by a 1750-hp. motor.

airfoil sections in use today are the result of NACA research. Much of the understanding of stability, flutter, and controls had the same origins.

Then came World War II. A fundamental high-level decision was made in Washington—that all hands had best join in the immediate job of providing planes of a quality that would help win the war. NACA turned to help with the more immediate problems of airplane development, to help solve the troubles as they appeared with prototype planes, and to help better the performance of production models.

Thus there was, during World War II, an almost complete moratorium on fundamental aerodynamic research. Of necessity, work done on

guided missiles, rockets, and the like suffered until after V-J Day. This resulted in the sentiment one finds expressed in many quarters of industry and government, of a post-war shortage of fundamental aerodynamic knowledge. Practice is currently riding too hard on the heels of theory. This in large part lies behind the present expansion program for the modification of old tunnels and construction of new types capable of conducting research in the new fields. Much catching up is in order. NACA and other research organizations, such as the Southern California Wind Tunnel, Massachusetts Institute of Technology, and Cornell Aeronautical Laboratories are vigorously at work to that end, although NACA continues to help with specific development problems when the facilities it has are the best available and when the Defense Department requests that help.

With basic research falling primarily to the lot of NACA, and to some extent to universities, development of specific components and planes becomes the primary concern of industry and of the Armed Forces. Thus the big centralized laboratories, primarily of the Air Force, are aimed at providing development facilities on a scale no private company can justify and at furnishing means for evaluating the constructions provided on contract by industry.

With this general concept of tunnel function in mind, the NACA, Air Force, and Navy, took action in 1946. It took note at war's end of the major lacks in this country's aerodynamic research and development facilities. Thus the Unitary Plan was formulated. This took into account existing university, industry, and government facilities and set forth the additional plant visualized as necessary for the next ten years. As originally set down, the plan was comprehensive and very expensive. It has since been abbreviated. However, the final Unitary Plan now being materialized does call for the construction of specific tunnels by NACA, the Air Force, and the Navy. Most of these are finished or under way. The Tullahoma project is one.

THE JUSTIFICATION FOR WIND TUNNELS

Wind tunnels are man's largest precision instruments. Accordingly they are expensive to build and to run. But, as one man experienced in the aviation field has said, "Sure they are costly, but not nearly as expensive as trying to get along without them. Just think what it costs to build 1000 planes of the wrong kind. In a war that can happen."

Wind tunnels are great time-savers. In a modern or a future war even a few days' time may be without price. Flight testing will, of course, always be necessary, but it can be greatly reduced by adequate work done in tunnels long before the prototype aircraft are wheeled onto the runway. Flight testing is expensive, too, not only in dollars but in pilots' lives. And wind tunnels give the indispensable opportunity to test components or scale models with succession of changes, changing

one variable at a time, all under controlled conditions with the ability to make precise measurements.

A modern military plane will go through five to ten models before it becomes obsolete. Each is more easily controlled, is more maneuverable, is faster, is able to fly farther on a given amount of fuel, or in other ways is better able to do the job than its predecessor. Much if not most of each improvement comes from what is learned about it in the laboratory. In the past, the difference between an optimum design and one second best, assuming the same power, might at most be only a few miles per hour. Today, the difference may be measured, literally, in hundreds of miles an hour.

Planes are flying faster, higher, and longer, and have new types of power plants. They are becoming so complex that to design a plane or missile or rocket from wholly fundamental considerations is hopeless. An NACA publication of a year ago succinctly stated the situation thusly: "We have yet to learn the extent to which detailed information about one specific design can be successfully applied to other designs." The airplane of today and even more so the airplane of tomorrow is designed in the wind tunnel.

UPWARD STEPPED LEADERS FROM THE EMPIRE STATE BUILDING

BY

B. F. J. SCHONLAND [1] AND D. J. MALAN [1]

SUMMARY

A new interpretation of the lightning discharge observations made by McEachron and others at the Empire State Building suggests that the polarity of the upward-moving stepped leaders found by them may have been negative, not positive as has been supposed, the current-recording equipment having failed in most cases to record the initial streamer stages of the discharge.

Important investigations of the current carried by lightning discharges to the Empire State Building, accompanied by Boys camera photographs of the streamers involved, have been made over a ten-year period by the research staff of the General Electric Company (**1, 3, 4**).[2]

About 75 per cent of these discharges were found to begin with an upward-moving stepped leader. This was often followed by a continuous flow of current ($\sim$250 amp.) carrying negative charge from cloud to ground and most frequently lasting for 0.27 sec. For half the flashes, however, the continuing discharge ceased earlier and further intermittent negative leader-return strokes of the usual kind discharged the cloud.

The steps of the first leader varied in length from 6 to 23 m., the average pause-times between steps from 19 to 30 μ-sec. and the effective velocities of leader advance (pilot-streamer velocities) from 0.6×10^7 to 7.1×10^7 cm/sec. (**3**). These quantities are in close agreement with those observed in South Africa for downward-moving negatively-charged stepped leaders (**6**).

From the records of the currents in the discharge and their time-variations, taken at the same time as these photographs, McEachron (**3, 4**) concluded that the upward step-streamers from the Empire State Building were positively-charged. This would mean that the parameters involved in the propagation of stepped leader streamers are exactly the same whether the streamers are positive or negative, a conclusion so unusual and unexpected as to need careful scrutiny.

It would appear that all the Empire State observations in which photographic and current observations were made on the same flashes date from the years 1935, 1936 and 1937 (**3**). The current wave-form was recorded by means of a crater-lamp oscillograph which required

[1] The Bernard Price Institute of Geophysical Research, University of the Witwatersrand, Johannesburg, South Africa.

[2] The boldface numbers in parentheses refer to the references appended to this paper.

125 amp. through the current shunt before it triggered. For this reason and possibly others, late triggering of the oscillograph seems to have been unavoidable and McEachron states (3, p. 185) that the first streamer currents were *not* recorded. In one case (3, p. 189) triggering is known to have occurred 0.008 sec. after the leader started upwards

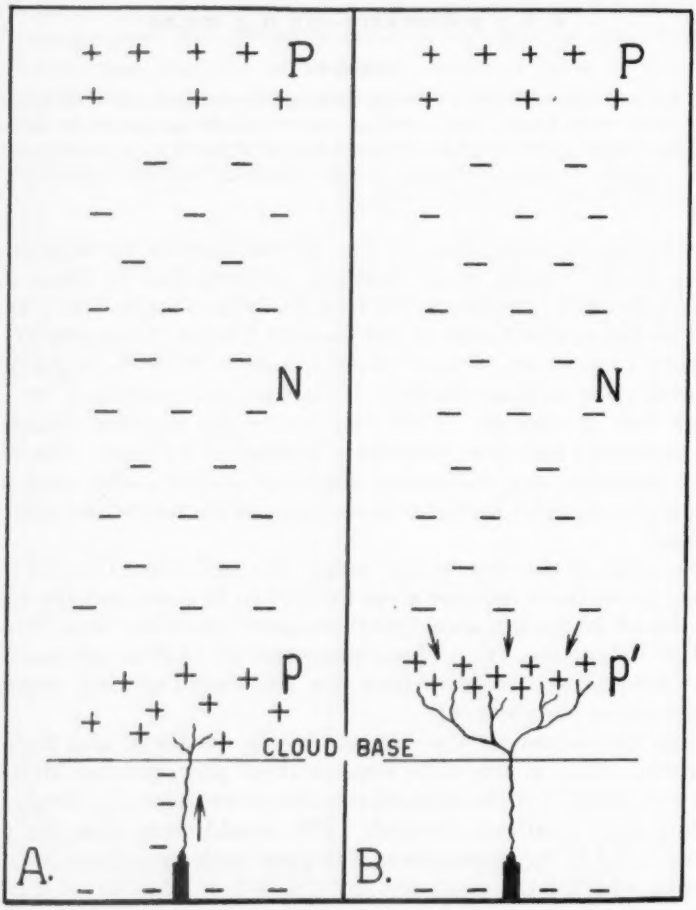

FIG. 1.

and in another (3, p. 196) it was very much later. There are no further details available about the delay time.

In this series of observations (1935–1937) the oscillograph when it started recording showed that negative charge was passing from cloud to ground. McEachron therefore concluded (3, p. 212) that the preceding missing portion of the record must have indicated current of the

same polarity. It is the purpose of this paper to show that this conclusion may have been wrong, in that it is not unlikely that the flow of current in the missing first 5 to 10 milliseconds from the start of an upward leader streamer from the Empire State Building would be opposite in sign to that registered later.

The usual distribution of charge in an active thundercloud during its mature stage is shown in Fig. 1*A*. The lower p charge is smaller in magnitude than N or P but it has been recorded by many writers that when the cloud is immediately above an observing station on flat ground, the component of the field due to p frequently approaches or exceeds that due to N (**5**, pp. 59, 60; and Malan, **2**).

The effect of the p charge is likely to be accentuated when a cloud of this kind passes over the Empire State Building, since the distance between p and the top of the Building as indicated by photographs of flashes is often as short as 0.6 km. instead of 2.0 km. as in South Africa. The p field should therefore often be sufficiently great for initial breakdown to occur as the result of an upward-moving negative stepped streamer from the Building. Travelling at 3×10^7 cm/sec., the velocity reported as most frequent by McEachron, this streamer would make first contact with p at a time 2 m.sec. after it started. It would then discharge p to ground without change in the sign of the current. The time occupied by this second stage can be estimated at less than 6 m.sec. since the radial dimensions of p are not likely to exceed 2 km. and the velocity of progress of the streamer inside the cloud will be at least as great as outside it, 3×10^7 cm/sec.

The current in this second stage will be extremely variable, since p is known to vary from zero to a maximum value estimated by Malan (**2**) of 10 coulombs. To pass this large quantity in less than 6 m.sec. would require a current of 1600 amp. or more; such currents are however likely to be unusual and a figure of less than 160 amp. is much more probable.

At the end of this second stage the p charge has largely disappeared and what is left is a conducting channel from the Building, topped by an ionized conducting region previously occupied by p. Owing to the proximity of N the top of the channel carries an induced positive charge p' (Fig. 1*B*). In the third stage of the discharge, breakdown as shown by the arrows in Fig. 1*B* will take place between p' and N by a J streamer process (Malan and Schonland, (**7**)) in the same way as it occurs in South Africa in the first stage of a discharge to ground. In the case of the Empire State Building, however, no downward leader is required to create a channel to ground since the channel already exists. The current in the channel is now reversed in direction and will produce the effects observed on the delayed oscillographic records of McEachron.

The current-time curve to be expected from this discussion is shown in Fig. 2. The portion OA represents the current flow during the up-

ward stepped leader stage, AB that during the discharge of P, BC the breakdown between p' and N, and CD the continuous discharge of N.

Some support for the views expressed above is afforded by later observations of the General Electric Company team in which they used cathode-ray oscillographs coupled to the shunt by a delay line. This enabled recording to take place as soon as the necessary triggering voltage appeared across the shunt (1). The value of the current required to trigger the oscillograph is not stated and this instrument too may have been subject to delays in starting. Of 13 discharges recorded with the new arrangement (4) two agreed in general form with Fig. 2, beginning with positive peak currents of 200 and 58,000 amp., respectively, and two had an uncertain start which could have been positive. The remainder would seem to have begun with negative current but are not discussed in detail.

Since these observations, most of which were made on day-time discharges, were not accompanied by Boys camera correlations it is not

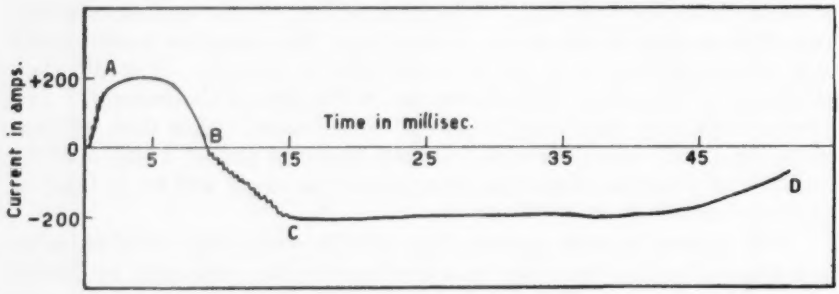

FIG. 2.

known how many of them involved upward leaders from the Building. Downward-moving negative leaders may have been present in the majority of cases. Oscillograph delays may also have occurred if the leader and p currents were less than 200 amp.

Mr. Hagenguth has very kindly supplied us with some unpublished information on the two p-type first discharges mentioned above. The 200-amp. current involved the passage of about 1.25 positive coulombs to ground, in agreement with what is expected to be the usual value of the p charge. The 58,000-amp. peak current (which must have involved a p charge of the order of several hundred coulombs) started about 25 m.sec. after the leader process. According to the explanation given above this would mean that the p charge was exceptionally large and was distributed over a region of much larger dimensions than usual.

In view of the interest attached to the stepped leader process as a form of gas discharge and to the sign of the charge it carries, it is to be

hoped that further direct tests of the polarity of the upward first leaders from the Empire State Building can be made. For this purpose field-change measurements of the usual type, recorded at a distance on a cathode-ray oscillograph, would suffice.

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Electronic Methods of Observing Stars.—Astronomers and electrical engineers at the University of Pennsylvania have joined forces in a concerted program to pioneer new electronic methods of observing the stars. To foster the development of new observation aids, the University has established a "working partnership" between its Department of Astronomy and its Moore School of Electrical Engineering. Under the plan, Dr. William Blitzstein, who was the first scientist to use the "pulse-counting" technique to measure star brightness has been appointed to the faculties of both departments.

One of the first projects of the new program will be completion of the Pierce Photometer, a measuring device based on Dr. Blitzstein's pulse-counting concept, but also embodying other innovations conceived by the late Professor Newton L. Pierce of Princeton University.

Astronomers have been measuring star brightness electronically for many years by measuring the electricity generated by starlight striking a photoelectric cell. The Blitzstein Photometer, instead of merely measuring the amount of current produced, counted the groups of electrons given off by the photocell—thereby yielding data in digital form. This made possible the Pierce Photometer, which is designed to make further utilization of electronics by printing its findings automatically, including the precise time of each electron count.

Moreover, the Pierce Photometer will solve an additional problem: To indicate how much of the light of a variable star has been lost in passage through the earth's atmosphere, it will observe two stars simultaneously—using a nearby star of known, constant brightness as a "yardstick" in measuring the light of the distant variable star.

Cylindrical Surface Roughness Scales.—New cylindrical surface roughness scales, designed as a standard of comparison by sight and touch for internal and external curved surfaces, have been developed by the General Electric Company's Instrument Department.

Consisting of two scales each, 6 in. wide and 2 in. long, the set is ideal for determining the roughness of surfaces produced by grinding, lapping, honing, superfinishing, turning, boring, drilling and others, according to G–E engineers.

Scale number one is capable of determining the surface roughness of 10 specific surfaces, an example of which would be that produced by grinding, lapping or honing, and superfinishing in the 4, 8, 16, 32, and 63 microinches categories. Surfaces on this scale are both external and internal.

On scale number two, typical surfaces, such as those produced by lathe and screw machine operations in the 16, 32, 63, and 250 microinches values, are represented by turned as well as bored surfaces.

Surface roughness on both scales is specified by numbers stamped on the units' sides which represent the arithmetic average deviation from the mean surface in microinches. For example: the number four equals four microinches roughness.

The new cylindrical surface roughness scales provide a standard objective reference by which engineers and draftsmen can designate the roughness and appearance of numerous finishes required for functional purposes.

In addition, the scales can be utilized by planners and shop mechanics in determining processing procedure, and in the selection of tools and equipment necessary to produce specific finishes required by specifications.

A DETERMINATION OF μ-MESOTRON REST LIFETIME AND A VERIFICATION OF THE RELATIVISTIC EXPRESSION FOR VARIATION OF LIFETIME WITH MOMENTUM *

BY

D. W. SEYMOUR [1] AND W. F. G. SWANN [1]

ABSTRACT

Measurements of cosmic ray intensity have been made simultaneously with counter telescopes at altitudes differing by about 3000 ft. and in locations which were the same within a distance of about 8 miles. Data were obtained for various thicknesses of lead absorber and with an additional thickness of absorbing material in the upper telescopes to compensate for absorption in the air column between the two sets of telescopes.

From the foregoing data the rest mean life values have been calculated on the basis of the relativistic variation of mean life with momentum for various ranges of momenta of the rays concerned. The theory[2] of the calculation allows for the continual change of mean life resulting from loss of momentum of the mesotrons as they pass through the air.

The value of the rest mean life obtained is 2.3×10^{-6} sec. and is constant over the ranges of momenta concerned, within the limits of accuracy of the data, thus confirming to this extent the relativistic expression.

The results are in close agreement with those of Rossi *et al*, but differ from the results obtained by Nielsen.

INTRODUCTION

Determinations of mesotron mean life have been made by various methods with varied results. Some methods involve knowledge of the relation between the absorption powers of great thicknesses of material.[3] Others have involved comparison of measurements made at different times at different altitudes and localities.[4] Moreover, there are wide differences between the results of different observers.[5]

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* Assisted by the Joint Program of the Office of Naval Research and the U. S. Atomic Energy Commission.

[1] Bartol Research Foundation of The Franklin Institute, Swarthmore, Pa.

[2] The theory of the method, which is similar in general principles to one given by M. Sands (*Phys. Rev.*, Vol. 77, p. 180 (1950)), was developed by the senior author (W. F. G. Swann), and the apparatus was designed under his direction by the junior author (D. W. Seymour), who also took the initial observations at Shenandoah Park. The subsequent routine data were taken by Mr. Harvey C. Taylor.

[3] T. H. Johnson and M. A. Pomerantz, *Phys. Rev.*, Vol. 55, p. 104 (1939); also M. A. Pomerantz, *Phys. Rev.*, Vol. 57, p. 3 (1940).

[4] B. Rossi, N. Hilberry and J. B. Hoag, *Phys. Rev.*, Vol. 57, p. 461 (1940).

[5] W. M. Nielsen, C. M. Ryerson, L. W. Nordheim and K. Z. Morgan, *Phys. Rev.*, Vol. 59, p. 547 (1941) give a value of 1.25 microseconds, while M. Ageno, G. Bernardini, N. B. Cacciapuoti, B. Ferretti and G. C. Wick, *Phys. Rev.*, Vol. 57, p. 945 (1940), give values in excess of 4 microseconds.

In view of the foregoing situation, the authors have planned and carried out *simultaneous* measurements at different altitudes in the *same locality*. Moreover, it has been felt necessary to interpret the observations in terms of a more precise theory than seems to have been used heretofore. The desire was also to verify the variation of mean life with momentum since, relativistic arguments notwithstanding, there could be sense to a situation in which the variation in question did not follow the relativistic form.[6]

EXPERIMENTAL ARRANGEMENT

The general plan was to operate cosmic ray telescopes at two different altitudes, with various thicknesses of lead absorbers between the trays. It was necessary to compensate the momentum absorption of the additional air above the lower telescope by inserting an additional equivalent thickness of lead in the upper telescope. The thickness of this "compensator" is determined by the following considerations. If L_1 is the thickness of the block of lead in the lower telescope, the total thickness L_2 in the upper telescope must be such that the momentum necessary to penetrate L_2 is equal to the momentum necessary to penetrate L_1 plus the air column between the upper and lower telescopes. If this condition is satisfied, then in discussing the penetration through the lead of thickness L_1, we have simply to consider that portion of the spectrum which, at the high altitude, would penetrate L_1 plus the air equivalent addition and attenuate it by mean life considerations in accordance with the calculations to be presented later. It will later be seen that the thickness of the compensator depends in principle upon L_1 as well as upon the mass of the air column. The dependence upon L_1 is, however, very slight, so that in practice, a single compensating thickness serves for all values of L_1 employed.

The compensator, which comprised 14 cm. of lead, was placed within the telescope. Arguments have been given for placing the compensator above the telescope,[4] these arguments being based on the fact that the air which is being compensated is also above the corresponding telescope. However, the real disturbing features, such as scattering, shower production, etc., play an entirely different role in the measurements for a thinly dispersed medium like air than they play for a dense medium. On the other hand, mesotron production in the lead itself[7] may be serious in the case where the lead is outside the telescopes, a conclusion which was strengthened by measurements of our own with lead above and inside the telescope, and in which the former gave greater measured intensities than the latter. Taking all matters into consideration, we decided to place the compensator within the telescope.

[6] The reasons for these considerations which are not primarily relevant to the present paper are given in a semi-classified report of limited circulation.

[7] M. Schein and V. C. Wilson, *Phys. Rev.*, Vol. 54, p. 304 (1938).

In practice, we used two independent telescopes at the upper level and two at the lower level in order to increase the statistical accuracy. The upper and lower telescopes were interchanged once during the observations, and the data subsequently recorded referred to all the observations taken at the upper or lower levels, respectively. It may be mentioned, however, that the counting rates of all the telescopes, when used under similar conditions, were found to agree within the limits of statistical uncertainty.

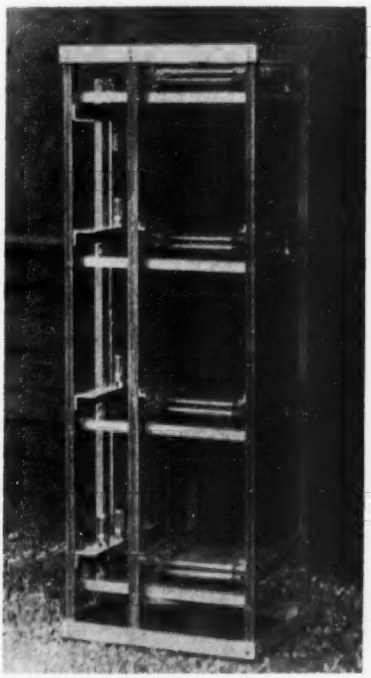

FIG. 1. Photograph of one of the telescope units. There are four trays of counters, 17 counters in each tray, straddled in a manner to increase tray efficiency.

Each telescope was arranged for fourfold coincidence observations, and the lead was distributed between the different counter trays. Figure 2 is a schematic sketch of one of the telescopes, shortened in length, however, for convenience of illustration. The details are given in the caption.

Of course, observations at the two altitudes were always taken under conditions in which the same amount of lead (apart from the compensator) was employed at each altitude.

The upper telescopes were located in Forest Ranger's Lookout Station on Hogback Mountain in Shenandoah National Park, Virginia (elevation 3,475 ft.), and the lower telescopes were located in a garage

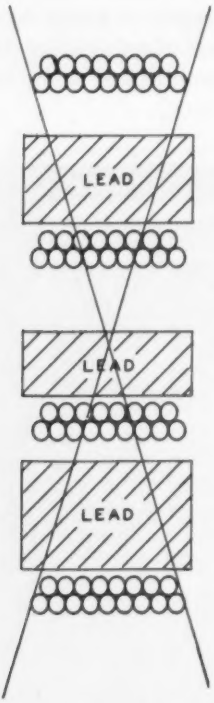

FIG. 2. A counter telescope.

Counter trays 12 cm. × 12 cm. sensitive area. 27 cm. between trays. Measured efficiency, 97 per cent. A Rossi coincidence circuit operates a thyratron and mechanical recorder. Resolving time for accidentals, 5×10^{-6} sec. Coincidence dead time, 5×10^{-8} sec.

in Front Royal, Virginia (elevation 490 ft.). The horizontal distance between the two stations was about 8 miles.

THEORY OF THE EXPERIMENT

The Compensator

If L_1 is the thickness of lead (in mass per unit area units) in the lower telescope, $f_1'(p)$ the loss in momentum (p) per unit (mass) thickness in lead, and if p_b is the momentum necessary for penetration of the lead of thickness L_1, then p_b is determined by

$$L_1 = \int_0^{p_b} \frac{dp}{f_1'(p)}. \tag{1}$$

The thickness of the upper block L_2 must be such that

$$L_2 = \int_0^{p_b + p_{hb}} \frac{dp}{f_l'(p)} \tag{2}$$

where p_{hb} is the momentum loss of a ray which, on passing through the column of air of thickness h, ends up with momentum p_b, the quantity h being the mass per unit of area of the air between the two telescopes. If this condition is satisfied, and if $F_2(p)$ is the spectral distribution function for the higher altitude, the rays which penetrate the upper and lower telescopes will be determined respectively by N_2 and N_1, where

$$N_2 = \int_{p_b + p_{hb}}^{\infty} F_2(p)\, dp; \quad N_1 = \int_{p_b + p_{hb}}^{\infty} \alpha_p F_2(p)\, dp$$

and where α_p is an attenuation factor determined entirely by mean life considerations.

If $f_a'(p)$ is the loss in momentum per unit (mass) thickness of the air, and p_h is the momentum, at entry, of a ray which, after passing through the mass thickness of air, has momentum p, we have

$$\int_p^{p_h} \frac{dp}{f_a'(p)} = h. \tag{3}$$

This determines p_h as a function of p and h, so that p_{hb} $(= p_h - p_b)$ is determined in terms of p_b and h. The values of $f_l'(p)$ and $f_a'(p)$ were obtained from the calculations of Rossi and Greisen.[8] The compensator thickness is, of course, $L_2 - L_1$; and in principle it depends upon p_b, but in practice the dependence is very slight.[9]

The Attenuation Through Mean Life Considerations

If Δn_2 $(= F_2(p)\, dp)$ is the number of rays having momentum between p and $p + dp$ at the higher altitude, then the group Δn_2 suffers

[8] B. Rossi and K. Greisen (*Rev. Mod. Phys.*, Vol. 13, p. 240 (1941)). These authors give dE'/dx' as a function of momentum, where E' is in electron volts, momentum is in e.v/c units, and x' is in grams per cm^2. To convert E' to m_0c^2 units, we multiply by $e/300\ m_0c^2$. To convert momentum to m_0c units, we multiply by $e/300\ m_0c^2$, and to convert dx' to dx, as measured in centimeters, we utilize the data obtainable from the Government's publication "The U. S. Standard Atmosphere."

Now in ordinary units, the momentum loss per centimeter, $-dp''/dx$, is related to the energy loss dE''/dx per centimeter by

$$\frac{dp''}{dx} = \frac{1}{\beta c} \frac{dE''}{dx}.$$

If p and E refer to m_0c units and m_0c^2 units respectively,

$$-f_a(p) = \frac{dp}{dx} = \frac{1}{\beta m_0 c^2} \frac{dE''}{dx} = \frac{1}{\beta} \frac{dE}{dx}.$$

[9] It turns out that for thickness of lead ranging from 10 cm. to 60 cm., the compensator thickness altered by only 4 per cent.

attenuation due to decay on its journey through the atmosphere according to the law

$$\frac{d}{dx}(\Delta n) = -\frac{\Delta n}{v\tau} \tag{4}$$

where dx is an element of path in centimeters, v is the velocity of the rays at a point in the path, and τ is the mean life for the velocity v. The momentum p in m_0c units is given by

$$p = \frac{v/c}{(1 - v^2/c^2)^{\frac{1}{2}}}. \tag{5}$$

Hence

$$v = \frac{pc}{(1 + p^2)^{\frac{1}{2}}}. \tag{6}$$

If we assume the relativistic expression for τ,

$$\tau = \frac{\tau_0}{(1 - v^2/c^2)^{\frac{1}{2}}} = \tau_0(1 + p^2)^{\frac{1}{2}}$$

where τ_0 is the rest mean life. Hence, from (4), (5) and (6) we have, on integrating over the path h, here expressed in centimeters,

$$\frac{\Delta n_2}{\Delta n_1} = \text{Exp} \int_0^h \frac{dx}{c\tau_0 p}. \tag{7}$$

Since, with $f(p)$ referring to the loss per centimeter of air,

$$-\frac{dp}{dx} = f_a(p) \tag{8}$$

we may write (7) in the form

$$\frac{\Delta n_2}{\Delta n_1} = \text{Exp} \frac{1}{\tau_0} \int_p^{p_h} \frac{d\zeta}{c\zeta f_a(\zeta)} \tag{9}$$

where p is the momentum above the lower telescope of a ray which has momentum p_h at the level of the upper telescope, and where we have changed the variable from p to ζ in order to avoid confusion with the limits of the integral. Since p_h is a function of p and the altitude difference h, the entire integral in (9) is a definite and calculable function of p, which we shall call $\psi(p)$, so that

$$\psi(p) = \int_p^{p_h} \frac{d\zeta}{c\zeta f_a(\zeta)} \tag{10}$$

and

$$\frac{\Delta n_2}{\Delta n_1} = \text{Exp}\,(\psi(p)/\tau_0)$$

$$\Delta n_1 = e^{-\psi(p)/\tau_0} F_2(p)\,dp.$$

If N_2 is the number of rays which penetrate the upper telescope with compensator, and whose momentum for penetration is p_2,

$$N_2 = \int_{p_2}^{\infty} F_2(p)\,dp \tag{11}$$

and if N_1 is the number of rays which penetrate the lower telescope,

$$N_1 = \int_{p_2}^{\infty} \Delta n_1 = \int_{p_2}^{\infty} e^{-\psi(p)/\tau_0} F_2(p)\,dp. \tag{12}$$

Let $\varphi_2(p)$ be some indefinite integral of $F_2(p)\,dp$. Then $\varphi_2(p)$ is undefined to the extent of a constant. However, for any choice of $\varphi_2(p)$

$$F_2(p) = \frac{d\varphi_2(p)}{dp}$$

and

$$N_2 = \varphi_2(\infty) - \varphi_2(p_2) \tag{13}$$

$$N_1 = \int_{p_2}^{\infty} e^{-\psi(p)/\tau_0} \frac{d\varphi_2(p)\,dp}{dp} = \left| e^{-\psi(p)/\tau_0} \varphi_2(p) \right|_{p_2}^{\infty} + \frac{1}{\tau_0} \int_{p_2}^{\infty} \varphi_2(p) e^{-\psi(p)/\tau_0} \psi'(p)\,dp. \tag{14}$$

Now although φ_2 is undefined to the extent of a constant, N_2 is obviously independent of the choice of the constant as may be seen from (13) or more fundamentally from (11). Now Eq. 14 does not explicitly exhibit N_1 as independent of the constant, but we know that it must be from (12). Hence, we can choose any constant A we please in (14). We shall imagine the constant to be chosen so that $\varphi_2(\infty) = 0$. In this case, we have for any value of p as corresponding to the upper telescope, the value of N for that telescope as given by

$$N = \varphi_2(\infty) - \varphi_2(p) = -\varphi_2(p).$$

Thus (14) becomes

$$N_1 = e^{-\psi(p_2)/\tau_0} N_2 - \frac{1}{\tau_0} \int_{p_2}^{\infty} N e^{-\psi(p)/\tau_0} \psi'(p)\,dp \tag{15}$$

where N in the integral refers to the number of rays which penetrate the upper telescope when the thickness of lead therein requires a momentum p for penetration.

Since the values of N are known over only a finite interval of p, the integral in (15) is unknown except between such limits p_{2a} and p_{2b} as those over which N is known. If, therefore, N_{1a} and N_{1b} refer to the numbers of rays which in the lower telescope penetrate two pieces of lead whose representatives in the upper telescope are penetrated by N_{2a} and N_{2b} rays of momenta greater than p_{2a} and p_{2b}, respectively, then

$$N_{1a} - N_{1b} = e^{-\psi(p_{2a})/\tau_0} N_{2a} - e^{-\psi(p_{2b})/\tau_0} N_{2b} - \frac{1}{\tau_0} \int_{p_{2a}}^{p_{2b}} N e^{-\psi(p)/\tau_0} \psi'(p)\, dp \quad (16)$$

where N, as already stated under the integral, refers to the upper telescope.

Assuming successive values of τ_0, Eq. 16 was tested, using graphical integration, until the τ_0 necessary to satisfy the equation was found.

An important feature of the above analysis lies in its allowance for the proper loss of momentum, and consequent variation of mean life during the passage of the mesotron through the air separating the altitudes of our telescopes. It can be shown that if the calculation had been made on the basis of an average momentum for any ray over the air journey, a significant change in the values of τ_0 calculated from the data would have resulted. In spite of the fact that an "integral method"[10] has been used in deducing the values of τ_0 from experimental data, the method makes no assumption as to the form of the spectral distribution of the mesotrons. This distribution dictates the values of N, but those values themselves depend only upon measurements.

Results

The measured absorption curves are shown in Fig. 3. The intensity is given in coincidences per minute and the absorber thickness in centimeters of lead. In the case of the upper telescope, the abscissa represents thickness in addition to the 14 cm. compensating absorber.

Table I shows various values of τ_0 computed for different regions of the absorption curve. These calculations are based on the value $m_0 = 196$ electron masses (1.00×10^8 e.v/c). We have chosen this value of m_0 because it is the value which has been used by most former observers with whose measurements it is of interest to compare our results.

[10] D. J. X. Montgomery, "Cosmic Ray Physics," Princeton, Princeton University Press, 1949, pp. 210–211.

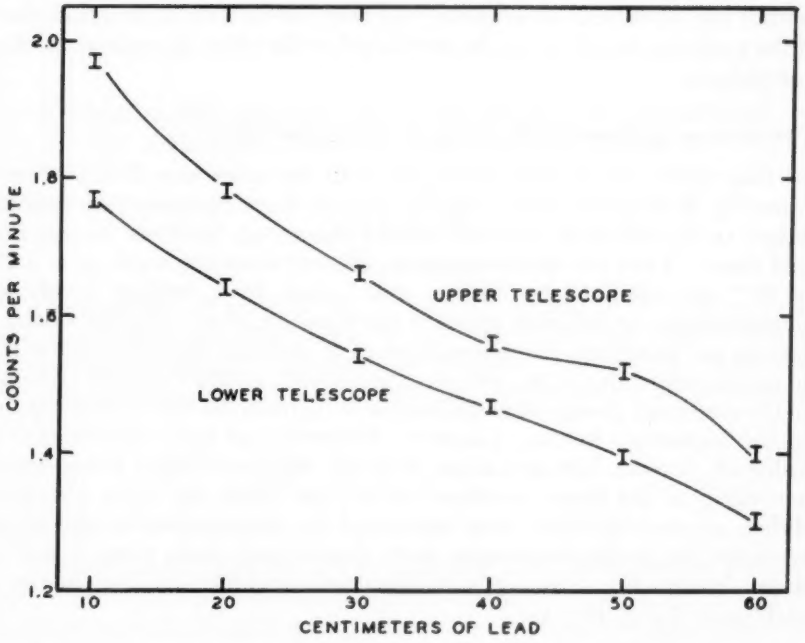

FIG. 3. Absorption curves measured at the two altitudes. For the upper telescope the thicknesses of lead are in each case 14 cm. greater than are recorded by the abscissae of the curves.

It is easy to show that with this value of m_0 a 10 per cent increase in m_0 corresponds to a 7 per cent increase in the value of τ, which would be calculated from the data. Thus, if we take the value of m_0 more usually accepted at present, namely, $m_0 = 212$ electron masses, the values of τ_0 given in the table would be increased by 5.6 per cent.

TABLE I.

p, m_0c units	p_h, cm.	τ_0, sec $\times 10^{-6}$
2.33–6.28	10–40	2.4 ± 0.8
4.95–9.10	30–60	2.2 ± 0.8
2.33–9.10	10–60	2.3 ± 0.6

The consistency of the values in the table for different portions of the absorption curve is interpreted as confirmation of the relativistic variation of τ with p, namely $\tau = \tau_0(1 + p^2)^{\frac{1}{2}}$. If the lifetime varied by some other law, for example, $\tau = \tau_0(1 + p^2)^{\frac{1}{4}}$, then it can easily be shown that the value of τ_0 for the higher values of p would be about twice the value for the lower values of p. Such differences in the values of τ_0 as exist for the different ranges of momentum are small, and well

within the statistical uncertainty, yet they are in such a direction that if the variation is real, it can be attributed to the effect of a non-decaying component.

Comparison of Results with Those of Other Observers

Our results are in close agreement with the value $\tau_0 = 2 \times 10^{-6}$ sec. found by Rossi *et al*,[4] using a similar method founded upon observations taken at two different altitudes widely separated, however, in position and time. They are, however, quite different from the result $\tau_0 = 1.25 \times 10^{-6}$ sec. obtained by Nielsen *et al*,[5] again by a method involving measurements at different times in the same locality. Nielsen's calculations are based on the assumption of a constant loss of momentum in passing through the air, whereas the present calculations take account of the continual change of mean life resulting from the loss of momentum of the mesotrons in their journey. However, we have recalculated a value of τ_0 from Nielsen's data as given, the calculation being made according to the theory outlined above, and while the value obtained differs appreciably from that calculated by Nielsen, and in the sense to make his results harmonize more closely with ours, there is still a wide discrepancy. Nielsen's results, as calculated by our method, yield $\tau_0 = 1.7 \times 10^{-6}$ sec.

Acknowledgments

We are indebted to Dr. Lyman J. Briggs, through whose good offices we secured the kind cooperation of Mr. Guy D. Edwards, Superintendent of the Shenandoah National Park, who put facilities, including the forest ranger's cabin, at our disposal. We are also indebted to Mr. R. G. Ovelman of the J. W. Meyers Company for the use of his Company's garage. The counters were constructed by Mr. A. G. Nester, and technical assistance was afforded by Mrs. F. J. Seymour, Mr. R. C. Pfeiffer and Mr. S. Berko.

A STRING-NET ANALOG FOR THE NUMERICAL SOLUTION OF THE EQUATIONS OF LAPLACE AND POISSON

BY

PETER L. TEA [1]

INTRODUCTION

The equation of Laplace, Eq. 1, and the equations of Poisson, Eqs. 2, 3, admit of algebraic solution, but only for boundaries suitable to the mathematical method. Initiated by Fourier, during 1800–1820, the method has been applied widely, but the limitations are still the same (1),[2]

$$\frac{\partial^2 z}{\partial x^2} + \frac{\partial^2 z}{\partial y^2} = 0, c, f(x, y). \qquad (1, 2, 3)$$

Numerical Methods

Mathematical solutions are general and best, but often not obtainable. Numerical solutions, good only for the numerical values of the boundaries assumed, are coming into ever increasing use in problems of engineering and physics.

All methods, the mathematical as well as the numerical, depend on a theorem due to Cauchy, according to which a solution is unique if it satisfies the differential equation at every point within and passes through the boundary, however the solution may be obtained or approached.

The Electronic Calculator

The following statement is quoted from information released March 27, 1953 by the International Business Machines Co.:

> The I.B.M. ELECTRONIC CALCULATOR 701 is the newest and most powerful high-speed electronic calculator. It will solve problems involving partial differential equations, ordinary differential equations, integral equations, matrices and combinatorial analysis. The calculators will rent for $11,900 monthly or more.

The versatility of the I.B.M. calculator, and there are also many other calculators, might well discourage mathematicians from the effort to extend general mathematical methods; but the I.B.M. calculator evidently is available to only a few.

---

[1] Department of Drafting, College of the City of New York, New York, N. Y.

[2] The boldface numbers in parentheses refer to the references appended to this paper.

Southwell's Relaxation Method

Three texts have been written by Sir Richard Southwell since 1935 (**2, 3, 4**), and many papers have been published by him and by his students, in which problems in Eqs. 1, 2, 3, and many others are solved (**5**). The differential equation is replaced by a finite difference equation at every node of the network. There are as many equations as there are unknowns. By a simple arithmetical process, sets of values of Z at the nodes are obtained which converge, more or less rapidly, to a sufficiently accurate final set. Finer nets will yield a set of values of Z at the nodes which will bring the net surface closer to the surface which represents the exact solution.

The Elastic Membrane Analog

Prandtl, 1904 (**6**), pointed out that the surface of a soap film across the boundary represents the solution of Laplace's Eq. 1, if both sides of the film are at the same air pressure, and represents Poisson's Eq. 2, if a pressure difference is maintained. The representation is only approximate; it is more accurate as the z scale is reduced, . . . the very quantity that is to be measured.

Griffith and Taylor, 1917 (**7, 8**), made important use of soap films to determine the stress concentration near the fillet radius in the corner of the keyway of a hollow shaft, and the variation of this stress with the radius of the fillet.

Thin rubber membranes have also been used.

Photoelasticity

Boundary values in the sum of the principal stresses can be obtained for two-dimensional problems from photoelastic patterns (**8, 9, 10**). The sum of the principal stresses satisfies the equation of Laplace inside the boundary, so the method of relaxation, or string net, can be used to determine the sum of the principal stresses within the boundary.

The String-Net Analog

The string net, see Figs. 1, 8, 10, 13, contains the boundary, and at every node the equilibrium position of the four string segments satisfies the second difference equation at that node. This second difference represents the first approximation to the differential equation of Laplace, Eq. 1. Any scale can be used for each of the three axes, particularly for the Z axis, which is the one to be measured.

The string net surface is the same as the one obtained by relaxation for the same problem and the same spacing, but does not require the often lengthy and laborious calculations.

I. THE TEMPERATURE DISTRIBUTION IN A SLAB OF CONSTANT THICKNESS, FOR THE STEADY TEMPERATURE STATE

In order to compare the exact mathematical solution with that obtained by the string net, and by relaxation, the following problem was chosen because it has a simple mathematical expression for the exact solution.

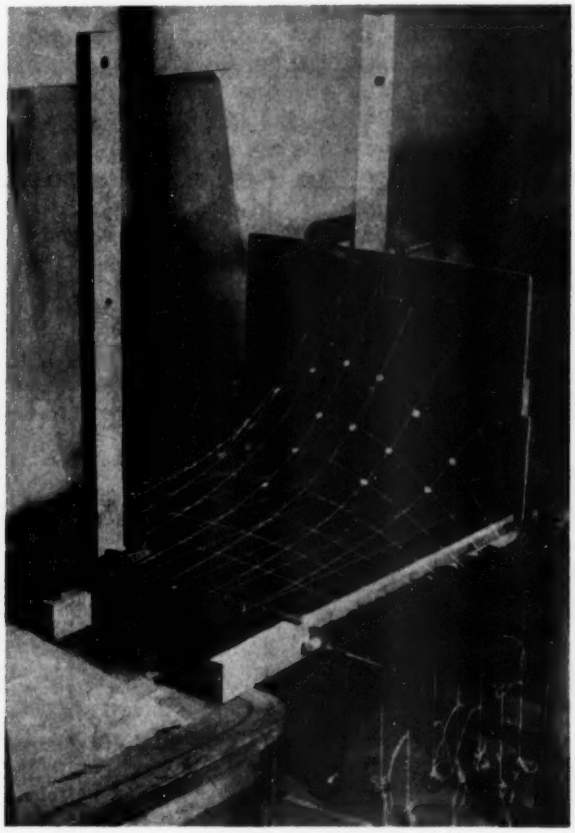

FIG. 1. String net for problem 1, showing the temperature distribution.

Problem 1. A rectangular slab of homogeneous material and constant thickness, of width π *from* $x = 0$ *to* $x = \pi$, Fig. 1, *and infinite in length, from* $y = 0$ *to* $y = \alpha$, *has the following boundary temperatures maintained, Eqs. 4. The upper and lower surfaces are completely insulated. The problem could be a corresponding problem in electrical potential.*

$$\begin{aligned} T &= A \sin x && x = 0 \text{ to } x = \pi,\ y = 0 \\ T &= 0 && x = 0,\ y = 0 \text{ to } y = \alpha \\ T &= 0 && x = \pi,\ y = 0 \text{ to } y = \alpha \\ T &= 0 && x = 0 \text{ to } x = \pi,\ y = \alpha \end{aligned} \tag{4}$$

The equation of Laplace, Eq. 5, must be satisfied,

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} = 0. \tag{5}$$

After a transient period the permanent temperature distribution is given by Eq. 6,

$$T = Ae^{-y} \sin x \tag{6}$$

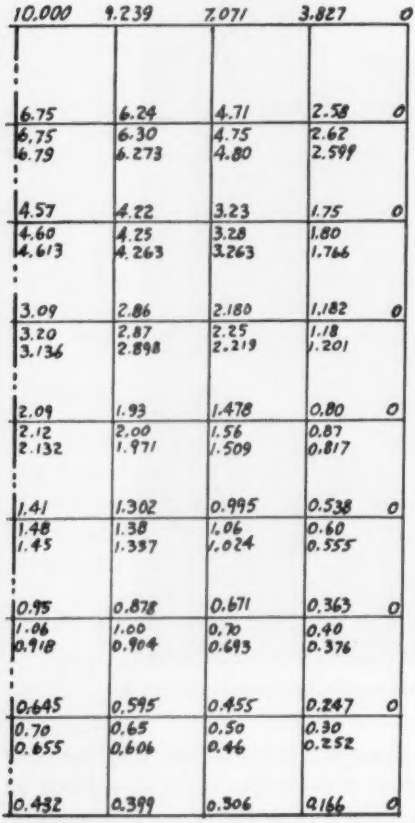

FIG. 2. Plot of the temperature distribution, steady state, for problem 1, with $h = \pi/8$, for the exact solution by string net, and by relaxation.

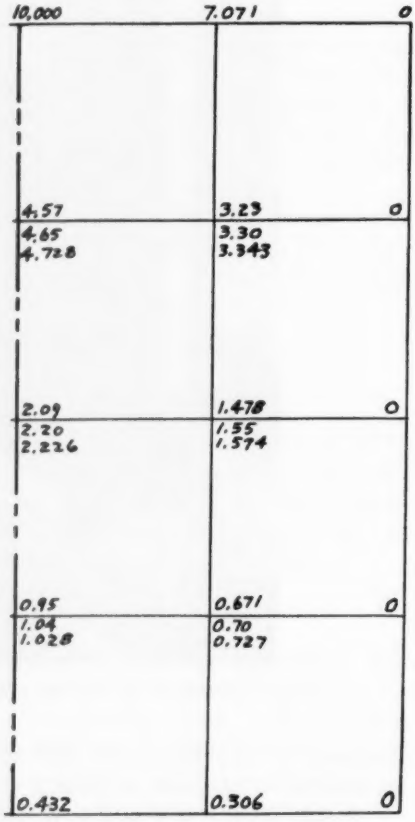

FIG. 3. Plot of the temperature distribution for problem 1, for $h = \pi/4$.

which satisfies Eq. 5 at all points of the slab up to and including the boundary. The surface, Eq. 6, is symmetrical about the plane $x = \pi/2$. Only half the surface is shown in Fig. 2, from $x = 0$ to $x = \pi/2$, in xy projection, with values of T given numerically at the nodal points, for $\Delta x = \Delta y = h = \pi/8$, and for $A = 10$. The upper numbers in Fig. 2 are the values of T for the exact solution, Eq. 6, at the nodes; under these numbers are the readings of the heights, in inches to 0.1 in. with an estimate to 0.01 in., at the corresponding node of the string net, Fig. 1. Under the second set of numbers are the values worked out to the third decimal by Southwell's relaxation method. The second set of numbers should agree with the third set, within the limits of accuracy in reading the heights of the nodes of the string net, and both sets should approach the first set of numbers as the fineness of the mesh is increased. The net was terminated at $y = \pi$, with small values calculated from Eq. 6, for T, thus making a closed boundary. For our purpose this is better than having the boundary extend to $y = 2\pi$ or more, where T is practically zero for $x = 0$ to $x = \pi$. Figure 3 gives the values of T for the same problem, for $\Delta x = \Delta y = h = \pi/4$.

II. THE STRING ANALOG

The String Form with Concentrated Loads; with Distributed Load; with Concentrated Loads Approximating the Distributed Loading.

The String Form for Concentrated Loads

In Fig. 4 a weightless string is loaded with weights $w_0, w_1, w_2, w_3, \cdots$ parallel to the Z axis and to the Zy plane, concentrated at and producing the nodes $Z_0, Z_1, Z_2, Z_3, \cdots$. The weights are equally spaced in y projection by distances $h = L/n$ apart.

From the polygon of Varignon, Fig. 5, Eqs. 7 and the form of the string are determined; conversely, if the form of the string and the value of T_0 be given, the polygon and Eqs. 7 can be obtained.

To simplify the formulae the origin will be taken at Z_0, and the zero segment of the string will be considered as horizontal, with tension T_0.

$$\begin{aligned}
-w_0h &= -W(y_0)h^2/2 = T_0[Z_1 - Z_0] &&= T_0\Delta^2Z_0 \\
-w_1h &= -W(y_1)h^2 = T_0[(Z_2 - Z_1) - (Z_1 - Z_0)] &&= T_0\Delta^2Z_1 \qquad (7)\\
-w_2h &= -W(y_2)h^2 = T_0[(Z_3 - Z_2) - (Z_2 - Z_1)] &&= T_0\Delta^2Z_2 \\
&\cdots\cdots\cdots

where α is the angle of the segment to the y axis; the value of α and T are given in Varignon's polygon.

The presence of the term $-W(y_k)h^2$ in Eqs. 7 will be explained.

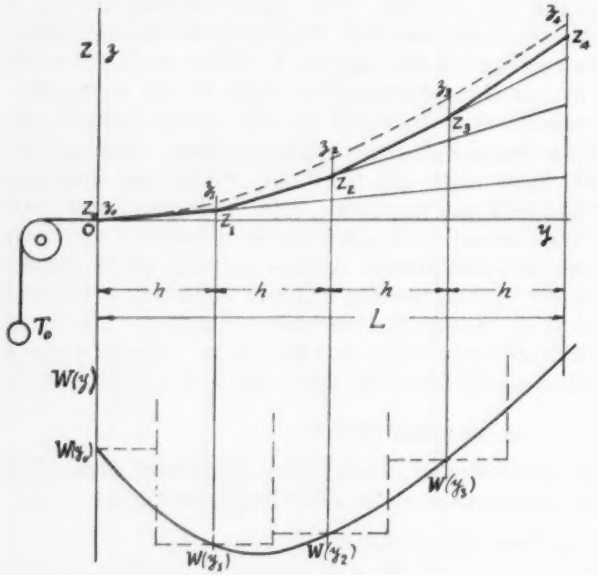

FIG. 4. The loaded string under distributed load, and under concentrated "equivalent" loading.

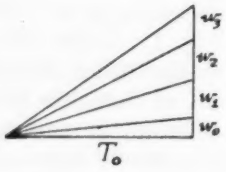

FIG. 5. The polygon of Varignon for the loaded string.

The String Form for Distributed Loading

For any load function $W(y)$, in units of weight per unit length of y, the equation to be satisfied is

$$-W(y) = T_0 \frac{d^2z}{dy^2} \tag{9}$$

and the form of the string is

$$zT_0 = -\int\int W(y)\,dy\,dy + Ay + B. \tag{10}$$

For $z = 0$ at $y = 0$, and $dz/dy = 0$ at $y = 0$, $A = B = 0$, and the string takes the form

$$zT_0 = -\int\int W(y)\,dy\,dy = f(y). \tag{10a}$$

It is to be noted that capital Z, the upper case letter, is used for the ordinate for concentrated weights, and small z, the lower case letter, is used for the ordinate for distributed loading, Fig. 4.

The String Form with Concentrated Weights to Approximate Distributed Loading

In Eqs. 7 the equality $-w_k h = -W(y_k)h^2$ indicates the assumed approximation to the distributed load within an interval, Fig. 4, so that the form of the string for concentrated loads shown in Fig. 4, for which the equations are Eqs. 7, is to be considered as the approximation to the curve shown dotted in Fig. 4 and given by Eq. 10*a*.

The forces $w_0, w_1, w_2, w_3, \cdots$, and the force function $W(y)$, were considered as weights, *intrinsically negative*, to simplify the presentation. This restriction is removed now. Where w is a weight, or $W(y)$ a weight function, $\Delta^2 Z/h^2$ and d^2z/dy^2 are positive, the curvature is positive, with center of curvature above the curve. Where w, or $W(y)$, acts in an upward direction, $\Delta^2 Z/h^2$ and d^2z/dy^2 are negative, and the curvature is negative, with the center of curvature below the curve, see Fig. 1, where the y strings have positive curvature, and the x strings have negative curvature, *everywhere*, it so happens, in Problem 1.

Comparison of Z_n from Eqs. 7 with z_n from Eq. 10a

From Eqs. 7, and for the boundary values assumed,

$$Z_n T_0 = -\sum_{0}^{p=n-1} \sum_{0}^{p} W(y_p)h^2 + W(y_0)\frac{h^2}{2}n \tag{11}$$

which approaches Eq. 10*a* as $n = L/h \doteq \infty$, and $h \doteq 0$.

The value of $Z_n T_0$ can be obtained by taking moments about the nodal point Z_n. For equilibrium,

$$Z_n T_0 = -W(y_0)\frac{h^2}{2}n - \sum_{1}^{p=n-1} W(y_p)(n-p)h^2. \tag{12}$$

To establish a comparison between the values of Z_n and z_n, a polynomial form, Eq. 13, is assumed for the load function,

$$-W(y) = a_0 + a_1 y + a_2 y^2 + a_3 y^3 + \cdots. \tag{13}$$

For distributed loading,

$$z_n T_0 = \tfrac{1}{2}a_0 y_n^2 + \tfrac{1}{6}a_1 y_n^3 + \tfrac{1}{12}a_2 y_n^4 + \tfrac{1}{20}a_3 y_n^5 + \cdots. \tag{14}$$

From Eq. 12, and with the approximation to the distributed loading and the boundary values in Eqs. 7 and indicated in Fig. 4,

$$Z_n T_0 = a_0 h^2 \left[\frac{n}{2} + \sum_{1}^{p=n-1} (n-p) \right] + a_1 h^3 \sum_{1}^{p=n-1} (n-p)p$$
$$+ a_2 h^4 \sum_{1}^{p=n-1} (n-p)p^2 + a_3 h^5 \sum_{1}^{p=n-1} (n-p)p^3 + \cdots \quad (15)$$

$$= \tfrac{1}{2} a_0 y_n^2 + \tfrac{1}{6} a_1 y_n^3 \left(1 - \frac{1}{n^2}\right) + \tfrac{1}{12} a_2 y_n^4 \left(1 - \frac{1}{n^2}\right)$$
$$+ \tfrac{1}{30} a_3 y_n^5 \left(1 - \frac{5}{3n^2} + \frac{2}{3n^4}\right) + \cdots \quad (16)$$

where $nh = y_n$.

From Eq. 16 and Eq. 14

$$\begin{aligned} &Z_n \to z_n \quad \text{as} \quad n \to \infty, \quad \text{and} \quad h \to 0 \\ &Z_n \equiv z_n \quad \text{for} \quad a_1 = a_2 = a_3 = \cdots = 0. \end{aligned} \quad (17)$$

For the latter condition Eq. 16 is a parabola and all the nodes are on the curve for distributed loading, for all values of n and h.

A Closer Finite Difference Approximation for $h^2 d^2z/dy^2$

The expansion of Eq. 10*a* about a point y_k of the curve in a Taylor series is given in Eq. 18,

$$z_{k\pm h} = z_k \pm z_k^{\mathrm{I}} h + \frac{1}{2!} z_k^{\mathrm{II}} h^2 \pm \frac{1}{3!} z_k^{\mathrm{III}} h^3 + \frac{1}{4!} z_k^{\mathrm{IV}} h^4 + \cdots \quad (18)$$

and the second difference is

$$\Delta^2 z\big|_k = z_{k+h} - 2z_k + z_{k-h} = 2h^2 \left[\frac{1}{2} z_k^{\mathrm{II}} + \frac{1}{4!} z^{\mathrm{IV}} h^2 + \frac{1}{6!} z^{\mathrm{VI}} h^4 + \cdots \right] \quad (19)$$

and

$$h^2 \frac{d^2 z}{dy^2}\bigg|_k = \Delta^2 z_k - 2\left[\frac{1}{4!} z^{\mathrm{IV}} h^4 + \frac{1}{6!} z^{\mathrm{VI}} h^6 = \cdots \right]. \quad (20)$$

The difference between the second derivative times h^2 and the second difference is a quantity of the fourth order in h.

From Eqs. 7 and 9

$$-w_k = -W(y_k) = T_0 \frac{\Delta^2 Z}{h^2}\bigg|_k = T_0 \frac{d^2 z}{dy^2}. \quad (21)$$

Equation 21 checks exactly if Eqs. 16 and 13 are used. The reason for the check is that Eq. 16 embodies the assumption of "equivalence" of concentrated loading which really is an approximation, in Eqs. 7.

The Effect of Unequal Spacing on the Approximate Value of the Second Derivative in Terms of Finite Differences

The same method of approximating the effect of the distributed load within an interval is used, as in Eqs. 7 and as indicated in Fig. 4. If in Fig. 4

$$y_3 - y_2 = b \quad \text{and} \quad y_2 - y_1 = h,$$

then

$$-w_2 = -\frac{h+b}{2} W(y_2) = T_0 \left[\frac{Z_3 - Z_2}{b} - \frac{Z_2 - Z_1}{h} \right] \tag{22}$$

and

$$-\frac{1}{T_0} W(y_2) = \frac{2}{(h+b)b} Z_3 - \frac{2}{hb} Z_2 + \frac{2}{(h+b)h} Z_1 \tag{23}$$

$$= \frac{d^2 z}{dy^2}$$

at node Z_2, approximately.

III. A STRING-NET ANALOG FOR THE NUMERICAL SOLUTION OF THE LAPLACE EQUATION, EQ. 1, AND THE POISSON EQUATIONS, EQS. 2 AND 3

The Equilibrium at Each Node of a Net

Figure 6 shows a series of y strings parallel to the zy plane, and uniformly spaced by distance h. The y strings are crossed by a series

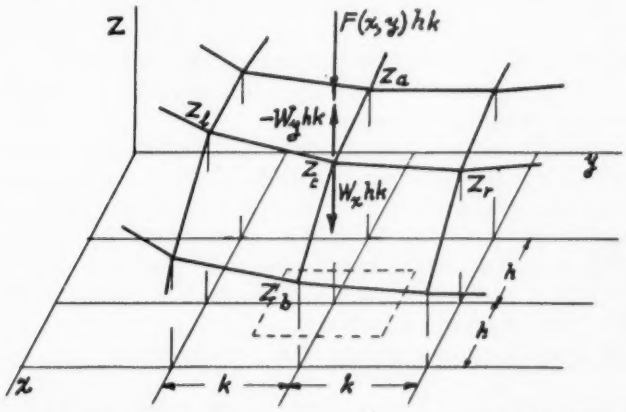

FIG. 6. The string-net approximation to the solution of Poisson's or Laplace's equation.

of x strings parallel to the zx plane, and uniformly spaced by distance k. The strings are continuous to the boundary, each fastened thereto at one end; the other end goes over a pulley, weighted to the proper tension, and is adjusted to just touch the boundary.

A field of force $F(x, y)$ parallel to the Z axis acts over the boundary. F is the force, at any point x, y, per unit area measured in projection on the xy plane.

The strings produce nodes at their crossings. At any node Z_c there are three forces in equilibrium, Fig. 6, all parallel to the Z axis.

$$F(x, y)_c hk - W_y[y, (x)]_c hk - W_x[x(y)]_c hk = 0. \tag{24}$$

$F(x, y)_c hk$ is the applied force at the node Z_c, $-W_y[y, (x)]_c hk$ is the reaction at the node Z_c, of the y string through Z_c, with parameter x, and $-W_x[x, (y)]_c hk$ is the reaction at the node Z_c, of the x string, with parameter y.

Each of the three forces may be directed upwards or downwards, but not all three in the same direction.

The string net must maintain contact of the x and the y strings at each node; one string or the other must be placed above to attain this result.

The strings must project orthogonally to the rectangular mesh on plane xy, *constituting the necessary and sufficient condition that the string reaction at each node be parallel to the Z axis.* This condition can be controlled fairly well by eye; more accurate control could be devised. Small buttons are threaded on the string in case it has a slope greater than the friction angle, to hang the cross thread to the proper position.

The value of the projection on plane xy of the tension in any x string is τk; the value of the projection on plane xy of the tension in any y string is τh. The projection on plane xy of the tension in the x and the y strings at any node will be τ per unit width in the direction of the projection on plane xy of the resultant of the tensions in the strings; thus the rectangular mesh on plane xy behaves like an elastic surface, under uniform stress.

The string net can be considered as representing two string surfaces in contact, each in the approximate, finite difference form, and more or less close to the surface which is the exact solution of the problem, depending on the fineness of the net, and on the complexity of the applied and of the two string load functions. One surface is composed of the x strings, the other of the y strings, both extended to the boundary, and in contact at the nodes.

For the x and for the y strings at Z_c, respectively,

$$-W_x[x, (y)]_c hk = \frac{\tau h}{k}[(Z_b - Z_c) - (Z_c - Z_a)] \doteq hk \left.\frac{\partial^2 z}{\partial x^2}\right|_c \tag{25}$$

$$-W_y[y, (x)]_c hk = \frac{\tau k}{h}[(Z_r - Z_c) - (Z_c - Z_l)] \doteq hk \left.\frac{\partial^2 z}{\partial y^2}\right|_c. \tag{26}$$

From Eqs. 24, 25, 26, and for $h = k$, Eq. 27 represents the first approximation in finite difference form to Poisson's Eq. 28, to within a

quantity of the fourth order in h. Equation 27 is the equation of equilibrium, in terms of the ordinates of a nest of five nodes, Fig. 6, of the string-net analog to Poisson's equation.

$$F(x, y)_c \frac{h^2}{\tau} + Z_a + Z_b + Z_l + Z_r - 4Z_c = 0 \tag{27}$$

$$F(x, y)_c \frac{1}{\tau} + \frac{\partial^2 z}{\partial x^2} + \frac{\partial^2 z}{\partial y^2} = 0. \tag{28}$$

For the Laplace equation, $F(x, y) = 0$ in Eqs. 28 and 27.

The Second Approximation to Poisson's Eq. 28—The Fox Method

Assuming a Taylor expansion in the neighborhood of a point on the surface $z = f(x, y)$ representing the exact solution, the correction of the fourth order in h is

$$-2\left[\frac{1}{4!}(z_x^{IV} + z_y^{IV})h^4 + \frac{1}{6!}(z_x^{VI} + z_y^{VI})h^6 + \cdots\right] \tag{29}$$

and should be added to Eq. 27, as was done in Eq. 21 for a single string.

In proceeding to a finer mesh, from distances h to $h/2$, and n^2 nodes to $(2n + 1)^2$ nodes, more than four times as many nodes must be relaxed. Instead, Fox thoroughly relaxes the coarser net, substitutes fourth differences for the correcting terms, Eq. 29, the relaxation of which forms a set of corrections to the values of the coarser net (12). Southwell prefers proceeding to the finer net (13).

Using a string net, when once set up to handle any boundary, proceeding to a finer net is simple, no calculations needed, no corrections at boundary points, and the convergence can be observed at the various parts of the net.

The Effect of Unequal Spacing at any Node on the Difference Equation for a String Net

Near the boundary one or two spacings may be different from the principal spacing h. In Fig. 7, the four spacings about the central node will be assumed all different. Using the same procedure for approximating concentrated loads as was used to obtain Eqs. 7 and 23,

$$F(x, y)_c \frac{A + B}{2}\frac{L + R}{2} + \tau \frac{A + B}{2}\left[\frac{Z_r - Z_c}{R} - \frac{Z_c - Z_l}{L}\right] + \tau \frac{L + R}{2}\left[\frac{Z_b - Z_c}{B} - \frac{Z_c - Z_a}{A}\right] = 0 \tag{30}$$

$$F(x, y)_c \frac{1}{2\tau} + \frac{Z_r}{R(L+R)} + \frac{Z_l}{L(L+R)} + \frac{Z_b}{B(A+B)} + \frac{Z_a}{A(A+B)} - Z_c\left[\frac{1}{RL} + \frac{1}{AB}\right] = 0 \quad (31)$$

which is the form taken by the difference equation at the node Z_c.

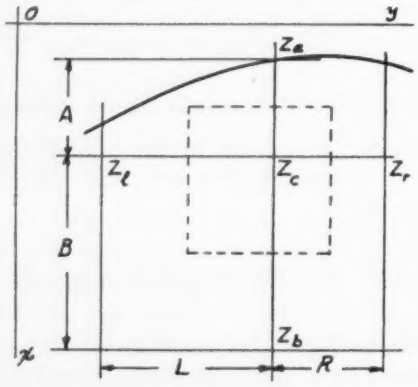

FIG. 7. The effect of unequal spacing at a node on the difference equation.

The Tension $\tau_x(y)$ in the x String as a Function of y, and the Tension $\tau_y(x)$ in the y String as a Function of x

$$\text{For } h = k, \text{ and } T_x = \tau_x(y) \text{ and } T_y = \tau_y(x), \quad (32)$$

the difference equation which indicates equilibrium at any node Z_c is given by Eq. 33, and is the first approximation to the partial differential equation, Eq. 34.

$$F(x, y)_c h^2 + \tau_x(y)[(Z_b - Z_c) - (Z_c - Z_a)] + \tau_y(x)[(Z_r - Z_c) - (Z_c - Z_l)] \quad (33)$$

$$F(x, y) + \tau_x(y)\frac{\partial^2 z}{dx^2} + \tau_y(x)\frac{\partial^2 z}{\partial y^2} = 0. \quad (34)$$

By varying τ_x and τ_y by finite differences, a string net can be constructed to approximate the surface which represents the solution of Eq. 34 for any closed boundary, approximately.

IV. STRING NETS APPLIED TO PROBLEMS IN LAPLACE'S EQUATION

Problem 1.

This problem is considered under Section I, Figs. 1, 2, 3. Note that in this problem the convergence is good, by comparing Figs. 2 and 3. The load functions are

$$\begin{aligned} -W_y[y, (x)] &= Ae^{-y} \sin x = \frac{\partial^2 T}{\partial y^2} \\ W_x[x, (y)] &= -Ae^{-y} \sin x = \frac{\partial^2 T}{\partial x^2}. \end{aligned} \tag{35}$$

The second differences divided by h^2 for both x and y strings are closer to the second derivatives than the corresponding values of Z and z at the nodes from which they were calculated, because the difference is a quantity of the second order in h, Eq. 20.

Problem 2, Figs. 8 and 9. A circular disc is maintained at temperatures of 20° at diametrically opposite points, and the rest of the periphery is maintained at 0°. Required the steady temperature state.

FIG. 8. String net for problem 2, showing the temperature distribution at the nodes, for $h = D/8$.

One symmetrical quarter of the disc is shown in Fig. 9, with $h = D/8$. The readings from the string net check with Eq. 27 with $F(x, y) = 0$. For $h = D/4$, Figs. 10 and 11, the heights of the nodes are greater for

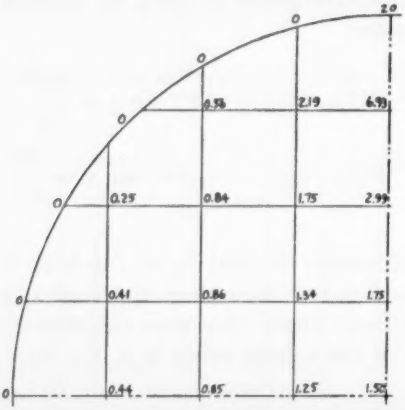

FIG. 9. Plot of temperature values obtained from heights of the nodes of the string net of Fig. 8.

FIG. 10. String net for problem 2, for $h = D/4$.

the same location, than for $h = D/8$ or $h = D/16$. The convergence is slow. By plotting values of Z, or of $\Delta^2 Z$, for the same location in Figs. 9, 11, and 12 with n as abscissae it will be found that near the

center Fig. 12 shows an approach to an asymptotic condition. Figure 12 was obtained by relaxation, for $h = D/16$.

The problem could be one in the flow of electricity, or a problem in the compressive stress of a disc by diametrically opposite compressive forces, valued at 20 units per inch, concentrated at opposite ends of a

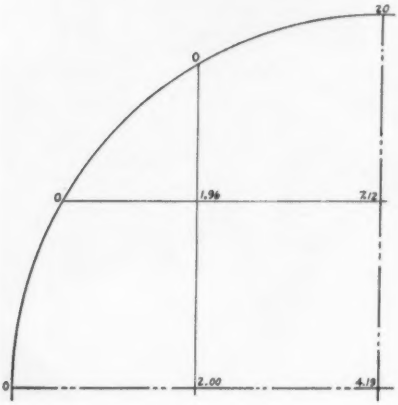

FIG. 11. Plot of temperature values from Fig. 10.

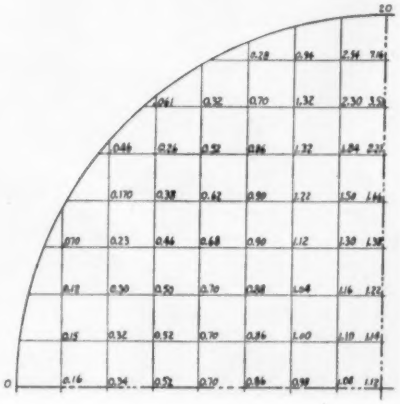

FIG. 12. Plot of temperature values obtained by relaxation, for problem 2, for $h = D/16$.

diameter. The sum of the principal stresses at the circular boundary is zero except at the compression points. The readings are the sum of the principal stresses at the nodes.

Problem 3, Figs. 13 and 14. A rectangular plate has two heat sources, at temperature 10°, at the center of opposite edges for a width equal to one quarter of the side of the square, or 1h, in Fig. 14. The rest of the perimeter is maintained at 0°. Only one quarter of the square is shown in Fig. 14.

The three problems presented satisfy Laplace's equation. Problems in Poisson's equation, for example in the distribution of stress in shear for prismatic rods under torsion, will be among those to be the subject of another paper.

To facilitate the formation of the string nets, the possibilities of a universal framework with horizontal rectangular mesh will be studied. Inside the framework any boundary should be quickly set up. Successive finer string nets would indicate the convergence. Finer local nets could be used. Large boundaries are practical, five or more feet across, which should facilitate the determination of stress concentrations at fillets, and the variations of such stresses with the fillet radius, merely by changing the radius in the boundary.

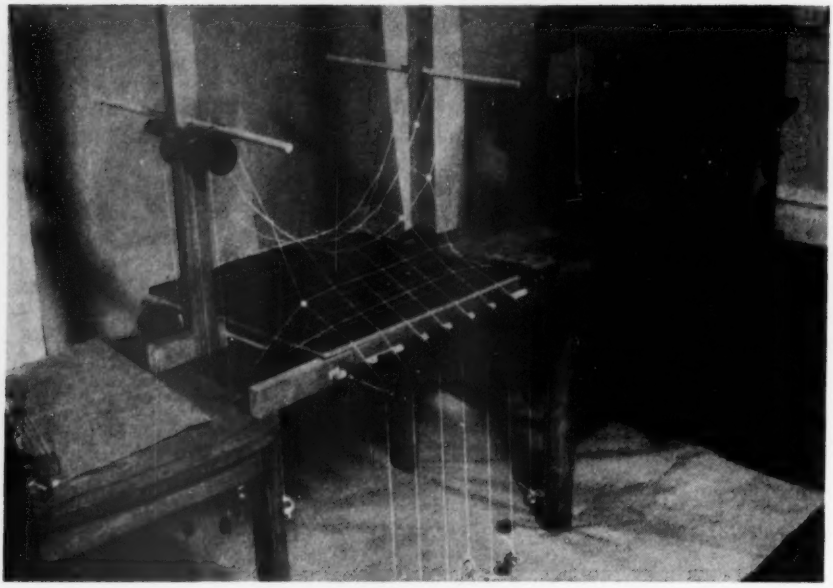

FIG. 13. String net for problem 3.

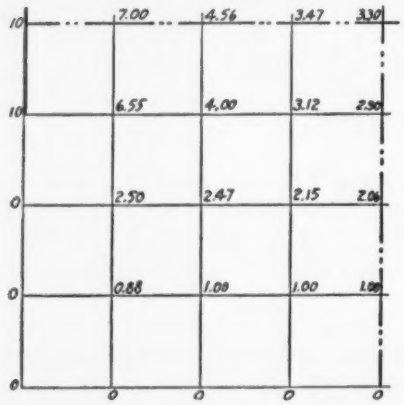

FIG. 14. Plot of temperature values obtained from the string net, Fig. 13.

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Laminated Wood Ladder.—A new laminated wood ladder, more than twice as strong as the standard type having solid wood beams, has been developed in answer to requests from fire department, utility company, and general industry personnel, preferring wooden ladders because of their greater safety factors.

Key to the new ladder's greater strength is its composite wood beam construction, made possible by modern glues and gluing techniques, and applied for the first time, in this country, to ladder construction. It is similar to that used by fabricators of glulam wood arches and trusses for the construction industry, and by shipbuilders producing modern wood minesweepers and other marine craft.

Developers of the new composite beam ladder are Engineering & Laminating Corporation, the Consolidated Gas, Electric Light & Power Company, both of Baltimore, Maryland, and Timber Engineering Company, research affiliate of the National Lumber Manufacturers Association.

Superior strength of the laminated wood ladder was demonstrated in tests, completed recently at the TECO laboratory, in which a standard 14-ft. solid beam ladder was pitted against two types of composite wood beam ladders.

The solid wood beam ladder supported a maximum load of 775 lb. before breaking.

One of the laminated beam ladders, composed of hickory, oak, and Port Orford cedar laminae, supported 1510 lb. before one hickory outer layer broke. Additional loads, well beyond specification requirements, failed to produce further breakage. The other laminated beam ladder, having greenheart instead of hickory and oak outer layers, supported 1580 lb. before showing signs of failure.

In addition to establishing strength factors, the tests showed that unexpected breaking is virtually eliminated in the laminated ladder, as its glue lines interrupt the continuity of wood grain in its cross section. Both laminated beam ladders gave loud warning sounds of cracking before their outer layers, only, broke, then continued to support greater loads for a longer time than would be required in actual use. In contrast, the solid beam ladder broke suddenly and completely, without warning.

The hickory-oak-cedar ladder was designed by Consolidated's chief engineer, H. L., von Hohenleiten, and the greenheart-cedar type was designed by Frederic C. Jay, vice-president and general manager of Enginering & Laminating, and TECO Technologist Norvelle G. Hundley, who conducted the tests.

Diamond Recovery.—The Industrial Test Laboratory at the Philadelphia Naval Yard has been giving special attention to diamond recovery from industrial diamond wastes. An electrostatic separator has been used successfully for separating diamonds from South African ore concentrates. Electrostatic separation depends upon the utilization of the difference between dielectric properties of diamonds and other minerals present in the ore concentrate. In electrostatic fields of the same intensity, diamonds will accept and retain a relatively large electrostatic charge in comparison with most other mineral substances. This property of diamonds is effectively used to separate them from other minerals.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS*

RADIATION MONITOR FOR ATOMIC TESTS

The National Bureau of Standards has developed a remote-control system which automatically measures radiation intensities and other variables in the vicinity of an atomic explosion and transmits the data by radio to a centrally located headquarters. The system was designed at the request of the Division of Biology and Medicine of the Atomic Energy Commission for use in nuclear tests. Though developed specifically for monitoring gamma radiation and weather conditions, it can be used with a wide variety of detectors to report many types of information. Except for the control station, the entire system is battery powered and will operate unattended for long periods.

The over-all design of the NBS radiation monitoring system was worked out by L. Costrell, G. Minton, and E. R. Saunders of the Bureau's nucleonic instrumentation laboratory. It permits the operator at the control station to select one of several data stations for transmission of data and to determine what particular type of information is to be reported. The radio link and the station interrogation system were designed and constructed by the Motorola Corporation and are based largely on their $\frac{1}{4}$-watt portable transmitter-receiver and other standard equipment.

The radio link is a frequency-modulated system operating in the VHF band between 162 and 174 megacycles. Since line-of-sight transmission is required at these frequencies, the link employs repeater stations located at positions of high elevation. Each repeater can handle information from 10 data stations, and each data station offers a choice of 10 different programs—each having several functions—which the operator can select for transmission to the control station. Thus, for example, one program might consist of station identification, several calibrations, and radiation intensity readings while another program might contain weather information.

Battery power is conserved by means of cycle timers at the repeater and data stations. The cycle timers operate in conjunction with a coder unit in the control station, which enables the control station operator to select the desired repeater and data stations. The cycle timers regularly turn the receivers at these stations on for two seconds out of every 20. If during the "on" part of the cycle the coder unit sends out a properly modulated signal indicating that the control station desires to communicate with a particular repeater or data station, the receiver at this station will be locked on and will no longer be controlled by the

* Communicated by the Director.

cycle timer. As cycle timers are installed at both repeater and data stations, the control station must transmit its coded signal for approximately 40 seconds in order to be sure to "capture" the repeater station and to have the repeater capture the data station.

After the repeater and a data station have been captured, the control station operator can then direct the data station to transmit the desired program of information. He does this by dialing the proper program number on the control console, which serves to energize the transmitter and modulator at the data station. The data station then transmits the desired program through the repeater to the control station. The information is transmitted in the form of a variable frequency covering the range of approximately 750 cps. to approximately 4 kc. At the control station this audio frequency is fed to a frequency counter, where it is counted and displayed in alternate one-second periods and also printed on a digital recorder. Calibration curves of radiation intensity or other quantities as a function of frequency are utilized in interpreting the frequency variations in terms of the measured data.

After the program has been completed, the data station receiver remains active for a short period, ready to accept further program challenges. The equipment is then automatically de-energized, and the cycle timer again assumes control, activating the receiver two seconds out of every twenty.

Each data station includes a transmitter-receiver, cycle timer, decoder, program selector, modulator, battery power supply, and detecting instruments. The decoder is a mechanically resonant device that activates the program selector when actuated by the proper incoming frequency. The program selector then receives impulses consisting of interruptions to the modulated subcarrier signal which are produced by the dialing mechanism in the control station coder console. These impulses occur at a rate of about 10 per second. The program selector utilizes a stepping relay and associated circuitry to advance one step for each impulse it receives. Thus, if the operator dials program No. 6, for example, six interruptions occur, causing the program selector stepper in the data station to advance to position No. 6.

After the program selector stepping relay has been advanced by the decoder to select the desired detector (radiation intensity, wind velocity, etc.), the output of this detector is routed to a function selector stepping relay. The function selector is advanced one position every 15 seconds by the cycle timer. Thus, the various functions—such as station identification, calibrations, and data from the detectors—are routed to the modulator in sequence to be transmitted to the repeater station. In the final step the modulator and transmitter are turned off though the receiver remains active for another two minutes to permit it to respond rapidly to further interrogation.

The modulator used is essentially an oscillator with a variable in-

ductance for controlling the frequency of oscillation. Negative feedback is used to give amplitude stability and to limit the variation of amplitude with frequency.

Radiation detectors were designed at the Bureau for this application, having a range of 0.02 milliroentgen per hour to 10 roentgens per hour. They were calibrated in the field using gamma radiation from cobalt 60 and a specially designed calibrating jig.

The repeater station consists essentially of a transmitter and receiver, with duplicate stand-by equipment. It also includes a cycle timer, decoder, and battery box. The repeater station is so designed that the control station operator can select either of the two receivers and either of the two transmitters in the instrument. This duplication of equipment is included since complete failure of the repeater would prevent reception from any of the data stations operating through it.

The control station contains duplicate transmitting and receiving equipments. Standard 30-watt transmitters are used. The two receivers are sharply tuned for high selectivity. In addition, where required, a cavity resonator can be inserted between the antennas and the receiver to give even higher selectivity.

The remote control console contains 12 push buttons and a dial similar to that used on telephone systems. Ten of the push buttons are for data station selection; the remaining two are used to select the desired receiver and transmitter at the repeater station. The dial is for choice of data programs.

The demodulated signal from the receiver is first amplified and then fed to a gated counter which counts the input cycles for a period of one second, displays the result for about a second, and then repeats the cycle. A digital printer records the output frequency as it appears on the frequency counter.

SAFETY INSTALLATION FOR HYDROGEN DISTRIBUTION LINES

The use of hydrogen gas in heat-treating and brazing processes is a standard laboratory practice which presents an inherent explosion hazard, especially if the gas is supplied from a remote reservoir and piped to the various operating stations. One general practice is to allow hydrogen to flow into an enclosure (such as a bell jar) and escape into the room. Safe operation depends on the hydrogen being above atmospheric pressure and maintaining a continuous outward flow. If the hydrogen pressure is allowed to fall below that of the atmosphere, air and hydrogen will mix. When about 7 to 73 per cent of hydrogen is in the mixture an explosion can occur if the temperature in the operating chamber is at approximately 500 to 600°C. While there are differential pressure controls and relay devices commerically available which automatically indicate a pressure change, these devices will not prevent an explosion from occurring within the operating chamber.

An installation that eliminates the hydrogen-air explosion hazard normally involved in such a use of hydrogen was recently devised by R. M. Carson of the National Bureau of Standards (now of the Diamond Ordnance Fuse Laboratories, Department of Defense). In this system, the inert gas, helium, is used to purge and flood the hydrogen lines automatically to prevent the admission of outside air in case the internal hydrogen pressure falls below atmospheric pressure. The assembly is basic enough to be adaptable to almost any type of hydrogen gas supply.

In the safety installation, a cylinder of helium is connected in the hydrogen network. The pressure regulator in the helium line is normally set from 10 to 20 pounds lower than that of the hydrogen line. The helium begins to flow only if the hydrogen-line pressure drops to that of the preset pressure of the helium. The hydrogen remaining in the system is then rapidly expelled until fully replaced by the safe helium; and a hazardous mixture of air and hydrogen is never allowed to take place within the potentially dangerous operating chamber.

This installation is being used with complete success in conjunction with hydrogen furnaces, with radiant ovens and radio-frequency heating setups, and with various devices and components treated in hydrogen-filled enclosures.

PORTABLE AIR INFILTRATION METER

A portable air infiltration meter designed by C. W. Coblentz of the National Bureau of Standards provides an improved means for determining the rate of air infiltration between different rooms of a building and the outside.

In the past, precise infiltration measurements have been restricted to laboratory installations because the equipment was cumbersome. The NBS instrument, however, being portable and compact, lends itself well to field investigations. It can be employed for tests in buildings without greatly inconveniencing the occupants and is expected to be of value in obtaining more comprehensive and precise data than those now available on that part of heating and air conditioning loads incident to infiltration in buildings.

Using a method developed by W. G. Marley of England, the change in concentration of a tracer gas, due to infiltration of outside air, is measured as an index of the air change rate. Since it has been shown that the number of air changes occurring during a given time is equal to the natural logarithm of the ratio of the tracer gas concentration at the beginning and at the end of the time interval, absolute concentration measurements are unnecessary. Only the percentage change in concentration need be measured, and this can be determined readily by noting the change in thermal conductivity of the tracer gas-air mixture as the test progresses.

It was found that helium is very satisfactory as a tracer gas because

of its high thermal conductivity compared to air. Small changes in helium concentration result in significant changes in thermal conductivity of the helium-air mixture which can be measured with sufficient accuracy using relatively simple instrumentation.

In each probe of the Bureau's meter are two matched and equally heated thermistors, which are connected to form two legs of a Wheatstone bridge circuit. They are installed in identical cylindrical cavities of a metal block to provide equivalent heat-absorbing surfaces. One cavity is air-filled and hermetically sealed while the other has small holes at the top and the bottom. This cavity is continuously ventilated through the holes by natural convection induced by the heated thermistor. Since the thermal conductivity of helium is about six times that of air, the thermistor in the ventilated cavity will be cooler than the other by an amount dependent on the quantity of helium "contaminating" the air.

The resulting change in the temperature of the thermistor causes an inverse change in its resistance. Thus any significant change in helium concentration, due to infiltration of outside air into the room under observation, unbalances the Wheatstone bridge circuit, and the effect can be read directly on a microammeter.

A practically constant heating current for the thermistors is obviously essential and, to obtain it, a variable transformer is used on the a-c. side of a fullwave selenium rectifier. This transformer is manually adjusted to compensate for changes in line voltage, and in the d-c. voltage caused by aging of the rectifier, and for variation in voltage drop across the rectifier resulting from use of a different number of probes during each test. Fluctuations in the line voltage after the adjustment is made are compensated for by using a voltage regulator tube in each probe circuit and by employing a variable resistance tube as the series resistor for the voltage regulator tube. With this combination, line voltage variations in the range from 70 to 120 volts cause less than 0.4 per cent change in the thermistor current.

The assembly is designed to simultaneously accommodate ten probes connected to one console. By use of a multi-position gang switch, it is possible to observe the changes in helium concentration in ten different rooms or areas during one test.

For infiltration measurements, the console is placed at a central location in the building under study, and a probe is mounted on a tripod near the middle of each room several feet above the floor. The probes are connected to the console cabinet by means of cables. After adjusting the heating current, at least one-half hour is allowed for all components to warm up to a steady-state condition. Next, the bridge circuits are balanced by adjusting the balancing resistors so that the meter reads zero in each case. Helium, in the amount of approximately one-half of one per cent of the total volume of the space, is then intro-

duced directly into the rooms. Thorough mixing is obtained either by use of desk-type fans or, when available, by means of a forced-air heating system.

Readings are taken from all probes used for the test at intervals of 3 to 15 minutes, depending on the rate of air change. A careful investigation indicates that the meter readings vary linearly with the helium concentrations, and that the accuracy is ample for present purposes, at concentrations less than one-half of one per cent of helium in air.

TO MEMBERS AND THOSE WHO KNOW THE FRANKLIN INSTITUTE

All of us associated with The Franklin Institute are gratified by the support given by its benefactors in the past. Without their generosity our privately endowed Institute would have been unable to serve industry, the professions, and the public as it has and should.

There is still a continuing and pressing need of contributions and bequests —both for general and specific endowment, and of income to be judiciously used. Your response will be most earnestly appreciated.

Checks should be made payable to The Franklin Institute, and sent to The Franklin Institute, Benjamin Franklin Parkway at 20th Street, Philadelphia 3, Pennsylvania.

Where property is transferred, title should be in the name of The Franklin Institute of the State of Pennsylvania for the Promotion of the Mechanic Arts.

We shall be glad to supply any additional information regarding gifts and memorials. Please write to the above address, attention of the Endowment Department.

THE FRANKLIN INSTITUTE

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COULSON, THOMAS: Some Prominent Members of The Franklin Institute. No. 1, Samuel Vaughan Merrick.

BACON, LESLIE R. AND JOHN H. WILLS: pH-Composition Relations in the System Na_2O—SiO_2—H_2O at 20°C.

LANGHAAR, H. L. AND M. STIPPES: Three-Dimensional Stress Functions.

SWANN, W. F. G.: The Acquirement of Cosmic Ray Energies by Electromagnetic Induction in Galaxies.

WATHEN, ROBERT L.: The Travelling Wave Tube—A Record of Its Early History.

MOON, PARRY AND DOMINA EBERLE SPENCER: Photometrics in Astronomy.

POMERANTZ, MARTIN A.: Primary Alpha Particles in the Cosmic Radiation Near the Geomagnetic Equator.

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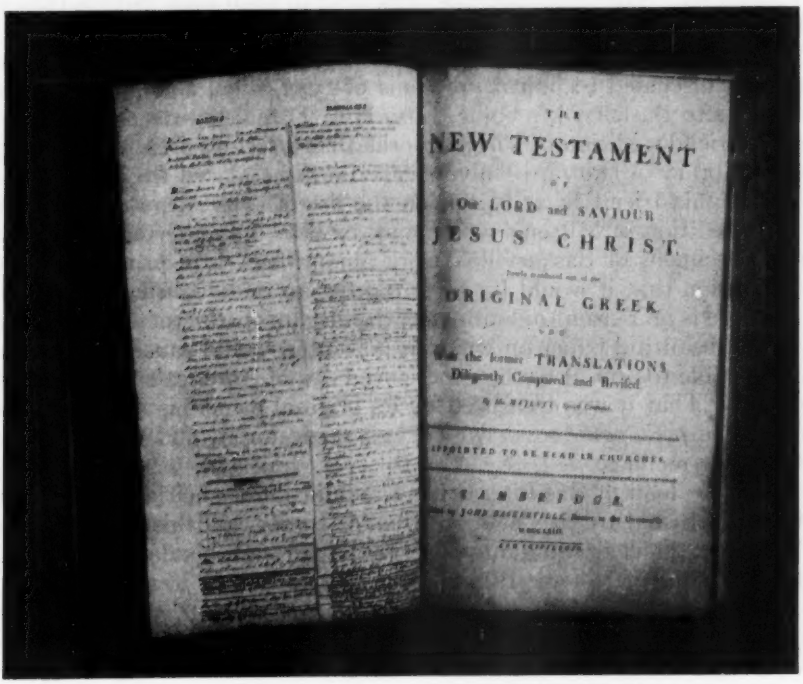
NOTES FROM THE FRANKLIN INSTITUTE MUSEUM

A. C. CARLTON, DIRECTOR

FRANKLIN BIBLE

We have had occasion to comment upon the widespread dispersion of Franklin relics which prevents anyone from seeing many of them without a great deal of travelling. Happily, this situation is being remedied as the Institute's collection grows with gifts and loans from descendants of the great man whose name the Institute bears. This collection has attained dimensions that makes a special visit well worth while. The collection has been enriched recently by the loan of an old family Bible that serves as a link between Benjamin Franklin and the present generation.

Originally purchased by Franklin in England, this imposing folio (it is of church lectern size) was a present to his daughter Sarah before her marriage to Richard Bache. The title page bears her name in the



The title page of the New Testament of Baskerville's Bible with, on the opposite page, the record of the Duane family.

authenticated handwriting of Franklin. The blank pages at the front of the volume contain a record of their family.

In the year 1830 the volume came into the possession of Deborah Bache, Franklin's granddaughter who married William J. Duane in 1805, editor of the *Aurora* and Secretary of State under Andrew Jackson. On the blank leaf of the Apochrypha is the lengthy record of Deborah Duane's descendants down to the present generation. Thus, this personal relic forms a link between Benjamin Franklin and a branch of his living descendants.

During the middle of the nineteenth century this Bible was used in the chancel of Christ Church, Philadelphia, for the reading of the lessons. Marginal notes in pencil support its use for this purpose.

This copy of the Holy Scriptures has an additional feature of interest which probably accounts for its selection as a gift by Franklin, the professional printer. It was printed in 1763 by John Baskerville, then printer to the Cambridge University Press, which shared the exclusive privilege of printing the Authorized Version with its sister university at Oxford and the king's printer. The books Baskerville printed are regarded as among the most distinguished examples of British typography. His type face has been held in such high esteem that it remains a favored design for book printing.

Franklin was a great admirer of Baskerville's work and the two printers discussed technical problems of type, inks, and paper during his visits to Baskerville's home, Easy Hill. Franklin was so impressed by his friend's edition of Virgil's works that he sent a presentation copy to the library of Harvard University. Later he placed the name of his Philadelphia friend Isaac Norris on the list of subscribers to the more famous edition of Milton's works and, in 1773, he undertook to distribute specimens of Baskerville's work among American printers, in the expectation that it would be advantageous to the English printer.

There is no reason to doubt that the elegant distinctness of the type and the beautiful paper on which it is printed would cause this edition of the Bible to appeal to the experienced eye of America's most famous printer. That it was treasured by its original owners is shown by the handsome *petit point* cover which was made for it, and on which the Bible now reclines.

For the loan of this interesting Franklin family heirloom the Institute is indebted to Dr. William Duane, Junior, and his brother John P. Duane, direct descendants of Franklin through his daughter Sarah, the original owner of the Bible.

NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION

ELLICE McDONALD, DIRECTOR

CORRECTION

JOURNAL OF THE FRANKLIN INSTITUTE, Vol. 258, No. 1, July 1954,
on page 50 in the Annual Report headed
The Biochemical Research Foundation (*Newark, Delaware*)
line 2 *for* 2-desoxy ribose nucleic acid (2DG)
read 2 desoxy-D-glucose (2DG)

RAPID REVERSAL OF SOME EFFECTS OF PROTEIN-FREE DIET

BY

J. O. ELY AND M. H. ROSS

When rats had been fed a protein-free diet for 30 days, the alkaline phosphatase activity (1) and the number of nuclei per gram (2) of rat liver were found to be increased approximately 100 per cent. The activity per cell remained constant. The number of mitochondria per cell was found to be decreased to about one-fourth of the number in the liver of rats fed a normal diet. Since the alkaline phosphatase activity per cell remained constant and the number of mitochondria per cell decreased, the alkaline phosphatase activity per mitochondrion increased (2). The altered values for the number of nuclei and for alkaline phosphatase per gram of tissue, the number of mitochondria per cell, and the alkaline phosphatase activity per mitochondrion have been found to return quickly to normal values when the animals were fed an adequate diet.

EXPERIMENTAL

Rats of the Wistar strain, 160–170 grams in weight, were fed a protein-free diet (dextrose 89%, corn oil 5%, salt mixture 4%, rice bran extract 2%, riboflavin 0.002%) for 30 days. They were then fed the Fox Food Blox diet of Allied Mills containing about 26 per cent protein.

At periods of 24, 48, and 72 hours after the change in diet, determinations were made of alkaline phosphatase of liver, the number of nuclei per gram, and the number of mitochondria per cell.

The number of nuclei per gram of liver decreased in 72 hours from the high values of the animals on the protein-free diet to the lower

normal values characteristic of well fed animals (Table I). The number of mitochondria per gram of tissue and per cell returned to normal values in 48 hours. The alkaline phosphatase activity per gram of tissue and per mitochondrion decreased as the number of cells decreased.

Rats on the protein-free diet lost weight and the livers became depleted of protein. As a result of protein depletion the volume of liver became smaller, and the number of cells per gram became greater, although there was some decrease in the total number of cells in the liver (3). When the rats were again placed on a diet adequate in protein, the livers of the protein-depleted rats quickly enlarged to the normal size and the number of cells per gram decreased; each cell became larger. As the cells became larger the number of mitochondria became greater; the alkaline phosphatase per mitochondrion became less.

TABLE I.—*Dietary Induced Changes in Number of Nuclei and Mitochondria and in Alkaline Phosphatase Activity of Rat Liver.*

	Protein-free Diet	Fox Food Blox Diet after 30 Days Protein-free Diet			Fox Food Blox Diet (Controls)
Period of diet	30 days	1 day	2 days	3 days	30 days
No. of rats	5	5	5	5	5
Av. wt. of rats	135 g.	140 g.	152 g.	164 g.	—
Nuclei/g. liver/10^{-8}	3.93±0.24	2.68±0.24	2.40±0.20	2.14±0.13	1.94±0.20
Mitochondria/g. liver/10^{-10}	5.5±1.46	8.2±0.6	13.1±0.6	12.8±0.7	11.9±1.17
Mitochondria/cell	160±39	310±29	560±127	601±29	623±87
Alkaline Phosphatase Activity					
mg. P liberated/hr./1×10^{6} cells	0.58	0.46	0.41	0.541	0.57
mg. P. liberated/hr./g. liver	2.22	1.26	0.98	0.92	1.08
mg. P. liberated/hr./1×10^{6} mitochondria	0.690	0.154	0.075	0.072	0.090

It may be concluded that the number of cells and the alkaline phosphatase activity per gram of tissue, the number of mitochondria per cell, and the alkaline phosphatase activity per cell in the livers of rats on a protein-free diet return to normal after 2–3 days on a protein adequate diet.

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NOTES FROM THE FRANKLIN INSTITUTE LABORATORIES FOR RESEARCH AND DEVELOPMENT

NICOL H. SMITH, DIRECTOR

PROJECTILE RECOVERY

BY

A. E. GIMSON

Ordnance designers have one collective wish: to see a projectile in the condition in which it leaves the gun muzzle. To bring this wish closer to reality, The Franklin Institute Laboratories made a survey* of methods now in use for recovering high-velocity projectiles with a minimum of damage. In the long history of the problem, several interesting schemes have evolved.

One of the oldest is firing into water, either in open bodies or tanks or even falling streams. Water is little used today because most projectiles are severely damaged by impact at the water surface. However, a modified form of water recovery is practiced with success in England; large caliber shells are fired over a beach at high tide so that they enter the water at a low angle and are retrieved when the tide recedes. Another method, used principally for recovery of fuses, is firing vertically over soft terrain; spinning projectiles land base-down and at relatively low velocities so that fuses are undamaged. A unique recovery device was developed at Johns Hopkins University during the war. Modified 37 mm shells were fired into a close-fitting steel tube 120 feet long. Simultaneously, compressed air was injected into the tube from the other end. When compression of the air brought the projectile almost to a stop, the pressure was quickly vented so that the missile came to rest in cotton padding at the end of the tube.

By far the most common technique is retardation of the projectile in dense media, particularly sawdust. Sawdust butts as long as 100 feet and 10 to 20 feet wide are used to recover 5-in. shells. Other materials have also been tried more or less successfully, including sand, cotton, snow, paraffin, etc. However, each has definite limitations which motivate the search for methods of broader applicability. Among the more promising ideas is the use of mixtures of substances of different densities, especially air and water. By varying the composition of the mixture along the path of the projectile, it should be possible to reduce the entry shock to a safe value and yet stop the missile in a short distance.

* This work was performed under contract with the Frankford Arsenal.

BOOK REVIEWS

SHIPS, MACHINERY, AND MOSSBACKS, by Harold G. Bowen. 397 pages, 15 × 22 cm. Princeton, Princeton University Press, 1954. Price, $6.00.

Do not allow the title of this book to deceive you. Admiral Bowen's account of his career in the Navy is no collection of salty sea yarns. He is a fighting man, dedicated through a long and productive career to making war on inefficiency. Anything that would not operate smoothly he would tackle with zest, and he has to record some memorable conquests. Forty-six years' service in the Navy provided him with ample opportunity to exercise his talent for fixing things. His special field was engineering, and the Navy soon found that out. They gave him ships with gremlins built into the engines. On a coal burner they gave him a black gang trained on oil burners. He got results from them all. Not all his troubles were with machinery. He could control personnel as illustrated by the manner in which he describes how he got a reluctant middle watch roused by applying a baseball bat to the bulging undersides of the hammocks, an effective method overlooked by the writers of Naval Regulations.

When he did not have refractory engines to discipline, he would white-wash a foundry or install a new book-keeping system. No kind of trouble came amiss to him. In fact, he seems to have enjoyed his existence in a sea of troubles. There is even an undertone of disappointment when he tells how his ship failed to run aground by drawing more water than was supposed to be in the channel at Buenos Aires. He cleared up so many messes on ship board or in Navy yards that Secretary Forrestal gave him the unofficial title of "the one man task force."

Admiral Bowen describes some famous controversies in which he was never far from the focal point. Not the least important of these relates to the struggle that was waged over high pressure high temperature steam. This marked the emancipation of turbine design from the domination of the Parson's design and resulted in achieving superiority for U. S. naval vessels just in time for them to meet the needs of a wartime emergency. At the same time he was advocating the installation of Diesel engines on submarines. The modest account of his efforts to redesign all the engines of the Navy reads as though it were a routine job.

Having described his achievements in this direction, Admiral Bowen tells of his "banishment" to the Naval Research Laboratory he had founded. By grace of his description of the original radar development we are presented with corrections for some misconceptions regarding its beginnings, and credit is given to the pioneer workers. The whole section of the book devoted to the achievements of the resourceful men whom the Admiral had gathered around him makes fascinating reading. One of the most interesting disclosures is their share in the early work on atomic fission.

A considerable portion of the book deals in detail with the Author's experiences in the controversial plant seizures and operation during World War II. This section displays Admiral Bowen's genius for clearing up messes on a grand scale.

This autobiography will not be read for its literary style, but what it lacks in grace it makes up for in a refreshing candor. The publishers claim he "pulls no punches," and while we can subscribe to that statement it must be said that there is not a vindictive sentence in the whole story, although many must have ben hurled at the author during his lifetime. Another point in the author's favor is the generous manner in which he distributes acknowledgments to his subordinates, a feature that brings to light the names of several men who worked in official obscurity.

Altogether, this is a modest account of a deeply interesting career that left a distinct mark upon the modern Navy, and it deserves to be read by everyone interested in naval affairs. Some important episodes are treated

with casual reference as mere routine, and this calls for careful reading.

If we may be permitted a mild complaint, it is that the early parts of the book are written in the vocabulary of a Chief Machinist's Mate and they left this reviewer hopelessly floundering among hand-hole gaskets and similar gadgets. Beyond this protest we have nothing but praise for this record of splendid achievement. T. C.

RADIATION BIOLOGY, edited by Alexander Hollaender. Parts I and II of Volume I, 1265 pages, tables, diagrams, illustrations, 16 × 24 cm. New York, McGraw-Hill Book Co., Inc., 1954. Price, $17.50 the set.

Volume I of *Radiation Biology: High Energy Radiations,* which is bound into two separate parts, is the first of a three-volume reference work. In press is Volume II of *Radiation Biology: Ultraviolet and Related Radiations;* in preparation is Volume III: *Visible Light.* Like its predecessor, Duggar's invaluable two-volume "Biological Effects of Radiation" that appeared in 1936 and which these volumes are to replace, *Radiation Biology* is again sponsored by the National Research Council but under the editorship of Dr. A. Hollaender. Also like its predecessor, it is certain to be a landmark in the field of radiobiology. Of the 21 contributors to this new volume, we find but two, namely, L. S. Taylor and R. E. Zirkle who were among the 46 contributors to the Duggar volumes.

The present volume of *Radiation Biology: High Energy Radiations* is broad in scope and parts of it are almost as deeply penetrating as the ionizing radiations in the analysis of radiobiology. Chapter 1, Principles of Radiological Physics, by U. Fano, expounds the properties, production and action of radiations, dissipation and penetration of radiation-energy in matter and the kinetics of radiation action. This chapter is written with a view to aid investigators in biology and medicine in the principles of radiological physics. Chapter 2, The Measurement of Ionizing Radiations for Biological Purposes, by L. D. Marinelli and L. S. Taylor describes radiation dosimetry giving an explanation of measurement of dose, dosimetric methods, ionization chambers and the practical aspects of radiation dosimetry. Chapter 3, Physical Principles Underlying Photochemical, Radiation-Chemical, and Radio-biological Reactions, by J. Franck and R. Platzman, describes the primary processes of photochemistry, radiation chemistry and radiobiology; reactions involving and following excitation and ionization; indirect and direct chemical effects of high-energy radiations on biological materials.

Chapter 4, Basic Radiation Biochemstry, by W. M. Dale deals wth fundamentals of the subject in which are considered the aims and achievements in this phase of research. Set forth in this chapter—as it is in some others—are the two basic concepts of radiation effects on living systems and frequently referred to as the theories of direct and indirect action. The older, classical direct action ("hit" or "target") theory holds that ionization is confined to specific molecules in a sensitive region or target of the cell or organism. In spite of the indirect action theory, which was presented by Fricke in 1934, the direct action theory was the one used almost exclusively to explain high energy radiation phenomena in living materials until very recently. We are indebted to the author of this chapter for his brilliant investigations in setting the indirect action theory on a firm foundation. This theory postulates the entire cell or organism and its environmental fluid as the target. Although both theories hold that ionizing radiations induce chemical changes, the indirect theory contends that fundamental chemical changes in the irradiated living systems are due to highly reactive substances found in and around the aqueous living materials which then react upon specific components of the cell or organism. In reality, this more flexible theory augments the earlier one instead of being compatible with it. Long before the indirect action was recognized, it was known that x-rays produce hydrogen peroxide when oxygen is present in water but not in its absence. Since biological material contains water and oxygen in varying amounts, these factors are uppermost in the minds of radiobiologists. Some would maintain that all or nearly all the biological effects of X radiation are due to hydrogen peroxide poisoning. But as so emphatically stated by Dale:

> Hydrogen peroxide is not the primary product of radiation but a consequence of the reaction of radicals with each other and with dissolved oxygen. . . . There is, however, a tendency to attribute too much weight to reactions with hydrogen peroxide. Many radiation effects may become less but do not disappear in absence of oxygen. Others are not affected at all either by the presence or absence of oxygen, or by hydrogen peroxide in concentrations built up by the radiation dose used. . . . Any tendency to overemphasize the hydrogen peroxide effect carries the danger of obscuring the progress made in understanding the mode of action of ionizing radiations, i.e., that these radiations can have an effect of their own.

Nevertheless, hydrogen peroxide production and its effect are important factors that must be evaluated in the irradiation of living material. It is of interest to note that in Duggar's 1936 volumes, hydrogen peroxide is barely mentioned; it is not listed in the index.

While it is evident that many chemical reactions intervene between the absorption of ionizing radiations and the biological effect, a better understanding exists although many gaps in our knowledge remain and must await further research.

Chapter 5, The Effect of X Rays on Systems of Biological Importance, by E. S. G. Barron, discusses the products of irradiation of water, the effects of ionizing radiations on oxidation-reduction systems, nucleic acids and proteins, enzymes, single cell and tissue metabolism and agents which protect against ionizing radiations. Barron emphasizes again the important fact that since most living cells contain abundant amounts of water and require oxygen, the indirect action concept is of importance to biologists but that both concepts—the direct as well as the indirect—may take place within the same system. Chapter 6, The Radiobiological Importance of Linear Energy Transfer, by R. E. Zirkle considers experimental variation and many other aspects of linear energy transfer as well as dose estimation of X, gamma and beta rays, fast neutrons and alpha particles.

Chapter 7, The Nature of the Genetic Effects Produced by Radiation, and Chapter 8, The Manner of Production of Mutations by Radiation have been written by H. J. Muller. In the opinion of this reviewer—a protozoologist engaged in X radiation of *Paramecium* and who is intrigued with the possibilities which Protozoa and related microorganisms may contribute to an understanding of radiobiology—these two chapters represent a classical account of the subject. Muller calls on his vast store of knowledge based on his own work and that of others dealing with the many aspects of X radiation of *Drosophila*. He discusses lucidly, factually and at times philosophically, the possible genetic effects on members of this genus and other organisms including man and the social order. Also outstanding are his sections dealing with the speeding up of evolution by irradiation and the practical applications of the action of radiation on genetic material.

Chapter 9, Chromosome Aberrations Induced in Animal Cells by Ionizing Radiations, by B. P. Kaufmann and Chapter 10, Radiation-induced Chromosome Aberrations in *Tradescantia*, by N. H. Giles, Jr., are comprehensive accounts which will be of special value to the worker concerned with the phenomena of chromosome aberrations. The remaining chapters with their titles and authors follow: Chapter 11, Immediate Effects on Division, Morphology, and Viability of the Cell, by J. G. Carlson; Chapter 12, Genetic Effects of Radiation in Mammals, by W. L. Russell; Chapter 13, The Effects of Radiation on Mammalian Prenatal Development, by L. B. Russell; Chapters 14 and 15, The Pathological Physiology of Radiation Injury in the Mammal. I. Physical and Bological Factors in Radiation Action and II. Specific Aspects of the Physiology of Radiation Injury, both by H. M. Patt and A. M. Brues. Chapter 16, The Hematologic Effects of Ionizing Radiation, by L. O. Jacobson; Chapter 17, Histological Changes after Irradiation, by W. Bloom and M. A. Bloom, and Chapter 18, Carcinogenesis by Ionizing Radiations, by J. Furth and E. Lorenz.

For the benefit of the reader, each chapter is prefaced by a synoptic outline of the contents and each chapter is concluded by an adequate bibliography. Useful, too, are the

name and subject indices. Biologists everywhere who are concerned with high energy radiations will be indebted to all the scientists who contributed to this monumental work and to the editorial skill of Dr. Hollaender. It is the kind of volume that is likely to be found on the book-shelf of most radiobiologists and in libraries throughout the world.

RALPH WICHTERMAN

TITANIUM AND TITANIUM ALLOYS, by John L. Everhart. 184 pages, diagrams, 11 × 17 cm. New York, Reinhold Publishing Corp., 1954. Price, $3.00.

Mr. Everhart points out in the preface that this Reinhold pilot book is intended for the person interested in the possibilities of applying titanium in the solution of his problems and will not appeal to the producers of titanuim or to those engaged in research and development. The author is overly modest, for even though this brief monograph is not intended for producers or research workers, it is sufficiently well written and contains enough material to be of general interest to all of those who have a moderate interest in titanium.

The widespread interest in titanium has developed primarily because of its physical properties. For a given weight it is stronger than any other structural metal. It is strongly resistant to corrosion and retains most of its strength up to 800° F. Consequently considerable research has been carried out on this metal and its alloys. The results of such reserach have not been compiled into one comprehensive volume and until such time, books such as this are of considerable use.

In Chapter Two a figure is shown entitled "Schematic Constitutional Diagram for Titanium Alloys." Three tables and one other figure are presented and discussed before this figure is referred to six pages later. Although the author realizes that there are many other constitutional diagrams for titanium alloys that do not fit this schematic description, he does not make this point clear and should have emphasized the fact that this was a schematic constitutional diagram for *some* of the more important titanium alloys.

A section on the properties of commercial titanium alloys is particularly good. Information is given here on the temperature dependence of such properties as tensile strength, yield strength, and elongation. In an attempt to condense this chapter and still present considerable material the author has included five tables and ten graphs. One of the tables and five of the graphs were not referred to or discussed in the text but this does not particularly detract from their usefulness.

Other subjects covered in this text pertain to the heat treatment, fabrication, machining, cleaning and application of titanium and its alloys. Much of this information is not readily available in the literature and thus increases the usefulness of this book.

R. L. SMITH

PRINCIPLES OF EXPERIMENTAL STRESS ANALYSIS, by Mark B. Moore. 146 pages, illustrations, 15 × 22 cm. New York, Prentice-Hall, Inc., 1954. Price, $3.00.

Principles of Experimental Stress Analysis is primarily a small handbook to be used as a guide in a college laboratory course on experimental stress analysis. It goes rather lightly over much of the subject. Some of the parts are much more easily comprehended if one already knows something of the subject. Generally speaking, the discussion of the various aspects of experimental stress analysis is strictly on an elementary level.

Professor Moore of Rutgers University properly begins his book with an explanation of the basic stress-strain relationships. He defines stress and strain, uniaxial stress, principal strains, and so forth; and the effect of notches and re-entrant corners on the stress distribution. Following an elementary discussion of the failure of engineering materials, Professor Moore describes the principles and operation of the various mechanical, optical and electrical strain gages, and the measurement of dynamic strain by electrical strain gages. He next discusses such other experimental methods of measuring strain as brittle coatings and photoelasticity, and the use of membrane analogy. The book is concluded with a number of suggested laboratory experiments to demonstrate the use of the various experimental stress analysis methods.

E. W. HAMMER

HEAT CONDUCTION WITH ENGINEERING, GEOLOGICAL, AND OTHER APPLICATIONS, by Leonard R. Ingersoll, Otto J. Zobel and Alfred C. Ingersoll. 325 pages, diagrams, 16 × 24 cm. Madison, The University of Wisconsin Press, 1954. Price, $5.00.

Although the title, "Heat Conduction," sounds highly specialized, this book points to the many applications of heat conduction theory which are related to our contemporary living. The theory applies to subjects as diverse as the cooling of concrete in the great hydroelectric dams and the roasting of a potato. The analysis of practically all situations involving heat conduction appears to be achievable through the application of existing theory.

Not only has the theory of heat conduction been worked out for the multitude of complex engineering, geological and other applications, but we have now had sufficient experience in testing these methods to encourage their use with considerable confidence. The reader's feeling of confidence in the analytical methods set forth by these authors is gained through example problems which have been worked out in the text and then compared with the results of the appropriate experimental procedure.

A fortunate aspect of this subject is the existence in Nature of unusually interesting examples with which to illustrate the various theoretical exercises. Of the greatest economic importance is the increasingly popular heat pump and the prospect of cheap year-round air conditioning through its use. These installations succeed or fail largely on the performance of heat exchangers which in turn depend upon heat conduction principles. The theory of the conduction of heat into and out of the ground by various arrangements is presented in a form suited to engineering analysis. Especially interesting possibilities such as power extraction from lava beds and geysers are investigated, and the numerical results may be quite as surprising to some readers as they were to the reviewer.

Other modern or futuristic developments such as the "solar house" are considered on an engineering basis. Some interesting side excursions are made to explain phenomena such as the "ice mine' where ice forms in summer and the temperatures are abnormally high in winter. This subject was mentioned to illustrate certain aspects of periodic heat flow.

These authors have presented a highly mathematical treatment of a none-too-glamorous subject in a most fascinating way by selecting fresh, modern problems to arouse the students' interest. C. W. HARGENS

ADHESIVE BONDING OF METALS, by George Epstein. 218 pages, illustrations, 11 × 17 cm. New York, Reinhold Publishing Corp., 1954. Price, $2.95.

The Reinhold Publishing Corp. brings to us in this thorough, concise pilot book an account of a method of joining metals together that is considerably underrated. The engineer (not connected with the aircraft industry) usually thinks of metal joining in terms of welding, riveting, or bolting and often neglects to consider adhesives as an alternative.

Dr. Epstein discusses the uses and advantages of adhesives at length. Some of the following advantages serve forcibly to point out the potentialities of the adhesive method of joining:

1. Ability to join dissimilar materials.
2. Elimination of need for high temperatures during joining.
3. Elimination of need for piercing of materials.
4. Ability to fasten articles to extremely thin metal structures.
5. Leak-proof joints (sealing action).
6. Structural advantages:
   a. Uniform stress distribution and increased service life.
   b. Reduced weight.
   c. Smooth surfaces and contours.
7. Reduced production costs.
8. Insulation and vibration-damping properties.
9. Corrosion resistance.

The author divides the basic materials into three classifications: (1) Thermomelting resins, (2) Thermoplastic resins, and (3) Elastomeric materials. He subdivides these further and then covers their chemistry and formulation quite thoroughly. It is interesting to note in the section on high tem-

perature adhesives that some materials are suitable for bonding metals in structures operating at temperatures of 500–600° F.

Enough detail is given in this book to enable the engineer to determine if an adhesive bond should be used and how to utilize an adhesive in the solution of a particular problem.

It is desirable in a condensed book of this type to offer the reader interested in more details a comprehensive list of references. It is doubtful if the selected list of only 19 references appended to the book will satisfy the average reader. R. L. SMITH

INDUSTRIAL STOICHIOMETRY, by Warren K. Lewis, Arthur H. Radasch, and H. Clay Lewis. Second edition, 429 pages, diagrams, 16 × 24 cm. New York, McGraw-Hill Book Co., Inc., 1954. Price, $7.50.

The first edition of this successful volume appeared during the mid-twenties in the McGraw-Hill Chemical Engineering Series. Since then, new problems have arisen in the chemical industry, improved computational methods have been developed, and the emphasis on certain educational techniques has shifted. Some of these changes are reflected in the second edition. Comparison with the first edition shows that the new volume contains three new chapters and that the old chapters were thoroughly revised in keeping with new developments. The theoretical aspects of stoichiometry are dealt with in two chapters: Introduction, Energy Balances and Equilibrium. Fuels and combustion are discussed in three chapters: Gaseous and Liquid Fuels, Solid Fuels, and Secondary Fuels. The two elements that brought about great transformations in the whole chemical industry are treated extensively in separate chapters: Sulfur Compounds and Nitrogen Compounds. The last five chapters are no less comprehensive: Lime and Cement, Fixed Alkalies, Metallurgy, Ceramics, and Design Problems.

The volume intends to provide the student of inorganic industrial stoichiometry with a variety of techniques applicable to process analyses. This aim is accomplished by a careful analysis of seventy-two "Illustrations." They cover such topics as the analysis of producer gas, Morgan and Winkler gas producers, the Glover tower for conversion of SO_2 into H_2SO_4, the layout of a synthetic ammonia plant, a rotary cement kiln, the manufacture of soda ash by the Solvay process, blast-furnace shaft-gas analysis, a formula for steel enamel, and the design of a tunnel kiln. The illustrative examples are replete with flow charts, block diagrams, and a wealth of analytical data in tabular or graphical form. The chapters end with a large number of graded problems some of which will tax even the ingenuity of professional industrial designers. Both illustrations and problems show that the authors are intimately familiar with the analysis of processes important to the inorganic chemical industry.

Computational methods employed are mostly simple and straightforward; they require only a knowledge of arithmetic and simple algebra. Emphasis is on the process balance while check computations assure the student that his results are free of error. Besides conversions from one basis to another, it is frequently necessary to solve simultaneous linear equations. An iterative method for solving simultaneous non-linear equations, the application of De L'Hôpital's rule, or a simple integration are the extent of more advanced mathematical tools used once or twice. The level of this volume would have been changed drastically by introduction of more advanced mathematical techniques, the likes of which the chemical engineer encounters with increasing frequency in industry. Since the authors have steered clear of such a course, the book will serve predominately undergraduate students or engineers studying industrial stoichiometry from the analysis of process operations and a variety of case problems.

CARL HAMMER

MICROWAVE SPECTROSCOPY, by M. W. P. Strandberg. 140 pages, plate, diagrams, 11 × 17 cm. London, Methuen & Co., Ltd.; New York, John Wiley & Sons, Inc.; 1954. Price, $2.50.

This book presents the information required to "obtain and interpret microwave spectroscopic data." The subject matter is limited, however, to the investigation of

energy levels of rotating molecules and omits discussion of electronic hyperfine structure and paramagnetic materials. Of the 112 pages of text, 86 are devoted to theory and 26 to experiment. Theory and experiment join two diverse fields: atomic physics and microwave electronics. The experimental portion seems slightly abbreviated and does not clearly indicate how the data should be treated. This may be the result of trying to keep the book within the limits of the Methuen Monographs.

In microwave spectroscopy, one studies absorption spectra of centimeter waves in various substances. Transitions between rotational energy levels require quanta having wavelengths in this centimeter range. Some knowledge of quantum mechanics is needed for an understanding of the theoretical sections of this book. It is a very compact and useful introduction to microwave spectroscopy. Included are an excellent bibliography, several appendices and a subject index. LEONARD MULDAWER

BOOK NOTES

FIBRE SCIENCE, edited by J. M. Preston. Second edition, 421 pages, diagrams, 15 × 22 cm. Manchester (England), The Textile Institute, 1953. Price: $6.00 (nonmembers); $5.00 (members).

The first edition of this book was based on a series of eighteen lectures delivered at the College of Technology, Manchester, in the first half of 1947. The revision for this second edition has involved both omissions and additions, the net effect on the size of the book being an increase of about twenty-five per cent. The chemistry of the synthetic fibers and related macromolecules is treated at length. The finishing and dyeing of both natural and synthetic textile fibers is discussed in terms of the chemistry involved; but the technological details of these processes are outside the scope of this work. Its central theme is the explanation of the properties of fibers on the basis of their chemical composition and physical structure, with a view to stimulating further investigation of the many unsolved problems in this field.

ALTERNATING CURRENT MACHINES, by A. F. Puchstein, T. C. Lloyd and A. G. Conrad. Third edition, 721 pages, diagrams, 16 × 24 cm. New York, John Wiley & Sons, Inc., 1954. Price, $8.50.

This new edition of the well-known text by Puchstein and Lloyd is about one-fifth larger than the second edition, but the arrangement is about the same. Changes have been made in the mode of presentation of some of the involved explanations. New material concerns adjustable-speed drives, rectifiers, and self-synchronous machines.

RAW COTTON PRODUCTION AND MARKETING, edited by A. F. W. Coulson. Volume I of *Manual of Cotton Spinning*. 222 pages, diagrams, 14 × 22 cm. Manchester (England), The Textile Institute, 1954. Price, $1.75.

This is the first of a series of seven volumes to be published by The Textile Institute at intervals over the next few years. All phases of the subject will be treated in this series, so that future technologists in the textile industry may use it as a basic text. This first volume consists of three sections entitled "The History and Structure of the Cotton Industry," "The Cotton Crop," and "Marketing Processes."

ELEMENTS OF FOOD ENGINEERING, Volume 3 Unit Operations 2, by Milton E. Parker, Ellery H. Harvey, and the late E. S. Stateler. 241 pages, illustrations and charts, 16 × 24 cm. New York, Reinhold Publishing Corp., 1954. Price, $6.75.

This volume completes a monograph on food engineering by continuing the discussion of unit operations started in Volume 2. Its six chapters treat evaporating, distilling, dehydrating solid foods, drying liquid foods, quality control, regulation of processes, coating and decorating, forming, packaging materials, packaging methods, and testing procedures for packaged products. The treatment in general is thorough in a qualitative manner; but aerosol packaging is given only passing mention and packaging for automatic vending machines is not discussed.

BIBLIOGRAPHY ON RESEARCH ADMINISTRATION—ANNOTATED, by G. P. Bush. 146 pages, 16 × 24 cm. Washington, The University Press of Washington, D. C., 1954. Price, $4.00.

This book contains more than 1100 annotated references, most of them selected from the literature since 1945. The search for them covered 90 periodicals. The references are grouped in eight "Parts." In addition, all of them are listed one or more times in the Topical Index covering 60 subjects. There is also a complete Author Index, including joint authors.

DATA BOOK FOR CIVIL ENGINEERS: FIELD PRACTICE, Volume III, by Elwyn E. Seelye. Second edition, 394 pages, illustrations, plates, 13 × 21 cm. New York, John Wiley & Sons, Inc., 1954. Price, $7.50.

Tables of data and statements of testing procedures in this handbook have been brought up to date. The two major additional topics are surveying and soil mechanics. The third edition, like the first two, should be well received by civil engineers, who appreciate the clarity with which the material is presented.

CURRENT TOPICS

X-Ray Microscope.—The General Electric Co. has disclosed development of an X-ray microscope that "looks inside" magnified specimens and is capable of wide use in medical science, biology and industry. The disclosure, at an international scientific meeting in London, climaxes many years of effort in the laboratories of the U. S. and European countries to develop a practical device of this kind that can be produced in quantity.

Sterling P. Newberry, electron-optics engineer of the G–E General Engineering Laboratory at Schenectady, N. Y., described the device at a six-day conference sponsored by the International Council of Scientific Unions. The paper was co-authored by Selby E. Summers, who assisted Newberry in development of the instrument.

The company's X-ray Department in Milwaukee, Wisc., will take over production of the device after further refinements in design at the Schenectady laboratory.

Newberry said the G–E instrument, which magnifies up to 1500 diameters, is expected to: aid in the development of new alloys and in studies of such things as corrosion and welding of metals; help researchers learn more about tooth decay, diseases of the bones and such other human ailments as mineral deficiencies and hardening of the arteries; assist in the study of such things as the covering or bonding quality of paints, adhesives and finishes; and, in some cases, provide a speedy substitute for chemical analysis.

For example, Newberry explained, scientists like to study heredity by experimenting with the tiny fruitfly because several generations can be studied in a short length of time and results of crossbreeding or atomic bomb exposure can be quickly determined. With ordinary microscopes, only exterior changes in the insect can be easily observed, but with the X-ray microscope changes in the internal organs can be observed equally well—and in three dimensions.

In the study of alloys, plastics and composition rubber, the X-ray microscope shows the mixture of the materials and can identify them by their relative X-ray absorbing power, the G–E engineer said.

To understand the principle of the X-ray microscope, think how you can cast a shadow on a wall by placing your hand near a lighted candle. The image of your hand is magnified in ratio to the distance of the candle from the wall and from the candle to your hand. But how sharp the shadow is depends upon how small the flame is.

By replacing the candle flame with an X-ray source, an enlarged X-ray image is obtained, and can be made visible by a fluoroscopic screen or an X-ray negative. But, as in the case of the candle, the sharpness of the X-ray image depends upon how small the X-ray source can be made. A conventional X-ray source cannot be made less than about one-eighth inch in diameter, and even a source as small as one 1000th of an inch gives magnification no greater than an ordinary reading glass.

In the G–E X-ray microscope, the X-ray source is only one 100,000ths of an inch—300 times smaller than the diameter of a human hair.

This is achieved by focusing the elec-

trons—tiny electrically-charged particles from which X-rays are made—through two electrostatic lenses, which are essentially doughnut-shaped metal rings to which voltage is applied. The magnified X-ray image thus obtained can be seen by the eye or photographed for permanent record.

Newberry said that while the idea of the electro-static lenses has been previously advanced, G–E's contribution was finding a practical way to use them.

He added that the instrument provides great stability for the longer exposures needed for high quality pictures, and is the first to employ a built-in camera that provides developed photographs immediately after a subject is exposed.

The G–E X-ray microscope is not affected by magnetic materials and therefore can be used in the study of steel and alloys.

The wave length of X-rays can be changed without changing focus, making it possible to vary the contrast of pictures. The instrument also has built-in safety controls to protect the operator from accidental exposure to X-rays.

Ultrasonic Energy Generator.—Rich-Roth Laboratories, Hartford, Conn., has announced the Rich-Roth "400"—a wide-range, 400 watt Ultrasonic Energy Generator, and with it a variety of transducers for production line or laboratory degreasing, emulsifying, impregnating, degassing, dispersing, coagulating, extracting, fragmenting, depolymerizing, and for medical therapy and research.

The 400-watt generator is continuously tunable over the frequency range from 10 to 1200 kc./sec. Ready selection of output impedances couples the generator to many types of piezoelectric and magnetostrictive transducers.

New types of Rich-Roth transducers include metal jacketed and lined fully enclosed water cooled treatment chambers in which the process materials are in contact only with metal surfaces. Another new type is a flanged flow-through chamber which can be bolted into a pipe line for continuous processing of materials. Expendable transducers for experimental purposes also are offered.

The combination of simple operation, wide range of frequency and output impedance, generous choice of transducers and sound field configurations are claimed to make the Rich-Roth "400" the first ultrasonic energy source equally suited for industrial and laboratory installation.

New Electric Rider Pallet Truck.—A new Warehouser electric rider low lift pallet truck capable of handling loads up to 4000 lb. has been developed by the Yale & Towne Manufacturing Company, Philadelphia, Pa. Designed for operation in five and six foot aisles, this truck is short in length and light in weight for low floor capacities and elevators.

Called the RP-4, the truck has a pallet fork lift of 4 in., and has a lifting time of approximately 5 sec. for full lift with full load. The over-all spread of the pallet forks are in standard widths of 25, 27, 30 and 36 in. Fork lengths are available from 36 in. to 60 in. in steps of 6 in.

A two position speed control lever located on the right hand side of the operator's compartment can be positioned for operator convenience in facing either direction of travel.

The Warehouser electric rider pallet truck has three speeds forward and three speeds reverse with time delay controls between speeds to insure smooth acceleration. Its rate of travel with no load is 5¼ mph.; with a full load, 4 mph.

Hoisting and lowering of loads is controlled by a lever conveniently located on the left side of the operator's compartment. Steering is controlled through spur geared reduction to drive unit with arc of steer over 200 deg. Rugged spring loaded dual caster wheels assure four point contact of truck at all times even on uneven floors and at the same time provide proper load distribution for stability.

The drive unit is a totally enclosed double reduction spur geared drive direct to drive axle which eliminates any adjustment for wear. The gear train operates in an oil bath with all rotating parts mounted on ball bearings.

The Warehouser electric rider pallet truck is equipped with deadman safety control treadle which instantly cuts off power and applies brake when the operator leaves the truck.

New Photocon Telemetering Counters.—Two new series of telemetering counters are offered by Photocon Research Products, of Pasadena, Calif. Both are small lightweight precision instruments which totalize and visually indicate shaft rotation in either direction in increments of $\frac{1}{10}$ revolution.

The PC-500 series potentiometer counters have an accurate electrical potentiometer on each counter wheel. The potentiometer resistance ratios are directly proportional to the visual indication.

The CC-500 series contacting counters have electrical contacts corresponding to each number on each wheel.

Both are said by the maker to be suited to many control and computing applications, as well as to the remote indication and recording of data correlated photographically.

Luminous Ceilings Combine Beauty with Usefulness (*Petroleum Newsnotes*).—Luminous ceilings that hide fire-fighting sprinkler systems, but fall out of the way if fire starts, have been made from an oil-derived vinyl plastic. The thin plastic strips are hung below the real ceiling, diffusing the rays of fluorescent lamps, which shine through in a bright, glareless light. Besides their attractiveness, they help muffle sounds in supermarkets, specialty shops, offices and banks where they have been used. Although they hide electrical conduits, air conditioning ducts, and other rough construction, they do not interfere with the sprinkler system required for fire protection. If a fire starts, the vinyl softens and falls out of the way.

Effect of Ultrasonic Energy on Fibrous Materials (*Newsletter for Wool Textile Executives,* Vol. 5, No. 7).—The use of ultrasonic energy as an aid to dyeing, scouring and other finishing processes has been suggested at various times. It is obvious that laboratory evaluation of the effects of such energy on fibers should precede pilot plant trials. In one such laboratory evaluation, frequencies of 10, 22, 30, 80 and 175 kilocycles were applied to various fibers in distilled water. Damage to specimens was determined microscopically.

The greatest damage to both fibers and yarns was found at 10 kilocycles. The damage decreased rapidly with increasing frequency. The degree and type of damage differed radically with the type of fiber. Cavitation (bubble formation) was greatest at 10 kilocycles and damage was greatest at the areas of greatest bubble concentration. Boiled and deaerated water produced less bubbling and less damage. There was no effect of temperature between 0° and 70° C. When fabrics were treated the accumulation of bubbles was more dispersed and they were damaged less than yarns and particularly fibers.

Bast fibers and hemp showed breakdown into individual fibers in 30 seconds and into fibrillae with diameters below 0.1 micron in 30 minutes. Jute showed extensive lengthwise splitting. Cotton fibers were torn apart in a few seconds, some appearing to be exploded from the inside by air enclosed in the lumen. Ordinary viscose rayon showed tears at right angles to the fiber axis but higher oriented, hollow viscose fibers showed lengthwise fiber splitting. Raw silk was partially degummed in 10 minutes' exposure. Wool was resistant to damage and even prolonged exposure merely removed some scales; however, in previously damaged wool, scales were removed rapidly. Hair was torn after 30 minutes, Perlon was extremely resistant.

In fabrics, the structure of yarns was first loosened, then the fibers were attacked to a degree close to that in the fiber form. Fabrics were resistant to damage at exposures up to two hours, with the exception of linen, which showed damage relatively soon.

Quick Method to Analyze Tung Products.—You can determine the oil content of wet or dry tung fruit, tung press cake, and filter cake rapidly and accurately by using an improved analytical method worked out by researchers R. S. McKinney and R. L. Holmes of the U. S. Tung Laboratory, Bogalusa, Louisiana. The Tung Laboratory is a part of the Department of Agriculture's Southern Utilization Research Branch, New Orleans.

The new method, which performs the determination within half an hour, should prove useful to processors for a rapid analysis of tung products to help in controlling operations. Researchers find results with their method in good agreement with those obtained by 4-hr. extraction with petroleum ether by the Official Method of the American Oil Chemists Society.

Here's the new procedure: It uses a high-boiling petroleum naphtha as the solvent. A finely ground sample of the tung material is mixed for 10 min. in twice its weight of petroleum naphtha. The solution of oil is filtered off, and its specific gravity determined. Oil content is estimated, either by reference to specific-gravity percentage tung oil tables or to curves prepared by the Bogalusa workers.

The procedure, including the reference curves, is reported in the May issue of the *Journal of the American Oil Chemists' Society* ("The Oil Content of Tung Products by a Rapid Petroleum Naptha Method"). A reprint is obtainable from the U. S. Tung Oil Laboratory.

Automatic Washing of Surgical Gloves.—Forty thousand pairs of soiled rubber surgical gloves a month are being washed at Cook County Hospital, Chicago, Illinois, in three Westinghouse Laundromat automatic washers. Hospital officials say four people working eight hours a day handle this washing load better, faster, and cheaper than the score of employes who previously washed the gloves by hand. Equally beneficial to the hospital is the fact that the employes released by the Laundromats make possible increased patient care.

This unique washing job is one of the first of its kind in the country. Its success demonstrates the practicability of using standard residential-type automatic electric washers to launder large volume and difficult to clean articles in hospitals and institutions.

Two-hundred pairs of surgical gloves are washed at a time. These are gathered in plastic bags just as the doctors stripped them off their hands —inside out—and are dumped directly into the Laundromats. A quarter cup of water softener and a half cup of non-sudsing detergent are added and

the machine turned on. Less than thirty-minutes later—following a pre-rinse, wash, and after-rinse cycle—200 pairs of clean surgical gloves are removed from the washer. The gloves are dried, powdered, packaged, and sterilized in the usual manner.

Cook County Hospital, with 3400 beds, is one of the largest hospitals in the country. The Laundromats are installed in the hospital's newly constructed central supplies and solutions department: a 24-hour a day operation employing 94 people to provide a myriad of materials and services for the entire institution. The department covers 10,000 sq. ft. and is considered a prototype of its kind, featuring such advantages as straightline production, tile walls, acoustical ceilings and up-to-date stainless steel equipment.

Combination Colorimeter-Spectrophotometer.—A combination colorimeter and spectrophotometer which produces high wavelength accuracy and spectral purity through use of a diffraction grating has been announced by the Bausch & Lomb Optical Co., Rochester, N. Y.

Called the Spectronic 20 because of its 20 mmu band pass, the instrument is designed for speedy, simple operation by laboratory technicians who need use only two control knobs in making routine colorimetric analyses. It also offers flexibility and a high degree of accuracy to research and quality control people concerned with the more complex analyses of spectrophotometry, the company said.

The Spectronic 20 analyzes any liquids or solids which transmit light by subjecting a sample to light of specified wavelengths. The degree of light transmittance is registered on a double scale, where readings may be taken in terms of either transmittance or optical density.

The operator can adjust the diffraction grating for any wavelength in the entire range of the instrument by turning a control knob, without being limited to available filters. Effective range is from 375 mmu (near ultraviolet) to 950 mmu (near infra-red), according to the company. For the range from 650 mmu to 950 mmu, an infra-red tube and filter are quickly substituted for the standard tube.

As a colorimeter, the instrument makes possible quick routine tests by subjecting the sample to fixed wavelength settings. Resulting readings can be readily interpreted as concentration values from predetermined calibrations supplied with the instrument.

More intensive study is possible by using the instrument as a spectrophotometer. Here the sample is subjected to light of the desired wavelengths to get transmittance and density readings for interpretative analysis and the construction of transmission and/or absorption curves.

Basic components are a built-in grating monochromator; a photoemissive detector to pick up the light which passes through the sample and transmit it in the form of photo-electric current; and a printed-circuit electronic amplifying system to build up the current so it will register on the scale.

To eliminate vibration problems and insure accuracy of readings, a rigid, die-cast base is used, together with a one-piece housing.

Non-Spinning Gyroscope (*Nickelsworth*, Vol. XX, No. 3).—The photographer thought it a strange assignment, taking movies of flies that couldn't fly. They tumbled and spun, came in for landings upside down, fell on their faces, wings or backs. Yet earlier, these flies had flown as well as any. Their dizzy acrobatics, he learned, were due to the rigidity of a

glued-up pair of rods beneath their wings. While these were unable to vibrate, the insects couldn't fly level. The pictures confirmed what Sperry Gyroscope engineers had discovered about a new kind of gyroscope, built like a tuning fork. The speed of a turn (called "rate of turn") affects the vibrating prongs of the fork, just as it affects the vibrating, club-shaped "haltere" rods beneath the wings of the fly. By a three-way electrical hook-up at the heel, middle, and tips, vibrating forks can be used as a gyroscope. Since the fork does not spin, it needs no bearings or motor, works without mechanical friction. From the very first working model, Sperry's designers could see that this apparatus had the potential of measurements impossible for the finest of their previous spinning, gyroscopic "rate of turn" indicators—on planes, rockets and guided missiles.

Vibrating heart of the Gyrotron* is its Inconel tuning fork, non-magnetic, corrosion-resistant, highly resistant to vibration-fatigue and mechanical shock. Small blocks of magnetic, 80 nickel-iron, "Nicobrazed" to the tips, furnish the electromagnetic drive that vibrates the tines. The Sperry Gyrotron can be made shorter than a cigarette. The present device weighs less than ten pounds, which compares more than favorably with spinning gyroscopic "rate of turn" indicators of equivalent accuracy. Nickel alloys make up more than 99 per cent of the metals in this new vibratory gyroscope.

"Building Block" Computer for Industry.—The Electronic Instruments Division of Burroughs Corporation, in Philadelphia, Pa., recently unveiled its Unitized Digital Electronic Computer (UDEC II), a large scale, general purpose computing system designed for scientific and industrial computation requiring high speed and accuracy. UDEC I, a somewhat slower sister computer, is at Wayne University, Detroit. Burroughs Laboratory Computer, an earlier (1950) experimental computer and the first of Burroughs' king-size machines, was torn down to make way for UDEC II.

Burroughs computers are unique in their building block construction. Each of the three was constructed from a large number of individual electronic chassis or pulse panels connected together into a logical system of computation. These electronic building blocks, called Unitized Pulse Control Equipment, are manufactured by Burroughs' Electronics Instruments Division and are sold as a basic product for a wide variety of test, control and computation purposes ranging from UDEC II, which contains 648 units, to more simple electronic instrumentation which may make use of two or three pulse panels.

It was this building-block design which permitted the construction of UDEC II in the remarkably short time of three months. The Electronic Instruments Division can duplicate this rapid construction time on future computers, since the basic building blocks are carried in stock as regular products.

While the use of these building blocks makes the machine more bulky, it increases the flexibility of the computer. Through changes in the cable connections between individual pulse units, Burroughs can easily modify the logic of UDEC II, adapt it to new input-output devices or even change it into an entirely different device such as a master control to monitor an automatic factory.

This versatility is an important factor in an age when the science of high

* Registered trade mark.

speed electronic computation is in a state of constant development. The building block principle virtually eliminates obsolescence in the UDEC-type computer. Today's faster, more versatile UDEC II contains the same pulse units used to build the slower Laboratory Computer four years ago.

The UDEC-type computer is probably one of few machines that can be tailor-made to fit the immediate needs and eventual budget of a user. Burroughs unitized pulse panels can be connected into a small-scale computation mechanism at relatively low cost. Simply by the addition of more pulse control units, such a small-scale computer can be gradually enlarged in scope and performance as additional funds are available.

The 648 pulse units that comprise UDEC II are stacked in 31 vertical channels in a C-shaped steel rack, 7 ft. high and 60 ft. long. In the center of the C formed by the machine are the various input and output mechanisms that feed information in and out of the computer. Here also is the desk-size control console from which the entire computer is operated.

The computer contains more than 3000 vacuum tubes, more than 7000 germanium crystal diodes as well as batteries of tiny magnetic cores. Close to 4000 cables (a total length of almost five miles) interconnect the basic units of the UDEC machine.

The machine accepts numbers up to nine decimal digits long. It handles these numbers in binary-coded decimal form—that is, each digit of the number is converted within the machine to its binary representation, though the number as a whole is manipulated as a decimal number. Use of the binary-coded decimal system greatly simplifies programming and operation of the machine, since neither the operator nor programmer need think in terms of the more difficult binary representation of numbers.

The UDEC II computer has a relatively large internal memory storage. It can store or memorize up to 5300 ten-digit words (numbers) on the periphery of its magnetic drum memory. Each of these 5300 addresses (positions on the drum) provides storage for a nine-digit decimal number, its sign (plus or minus) and check number. Inside the machine the sign and check number are combined into a single digit.

The Unitized Digital Electronic Computer, like all other man-made machines, is not infallible. But automatic error-detection circuits within the machine ring a bell when faulty electron tubes or other components cause mistakes in computation. The operator halts the machine, finds and replaces the faulty component. Then the computer goes back to work. The task of finding and replacing a faulty component is greatly simplified by the unitized construction.

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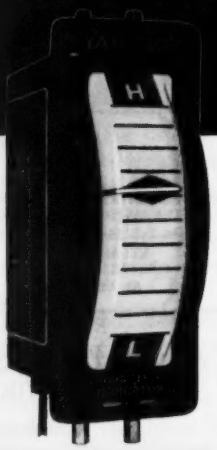

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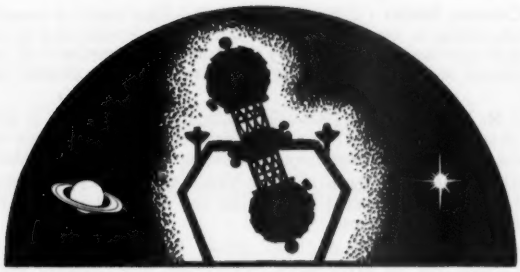

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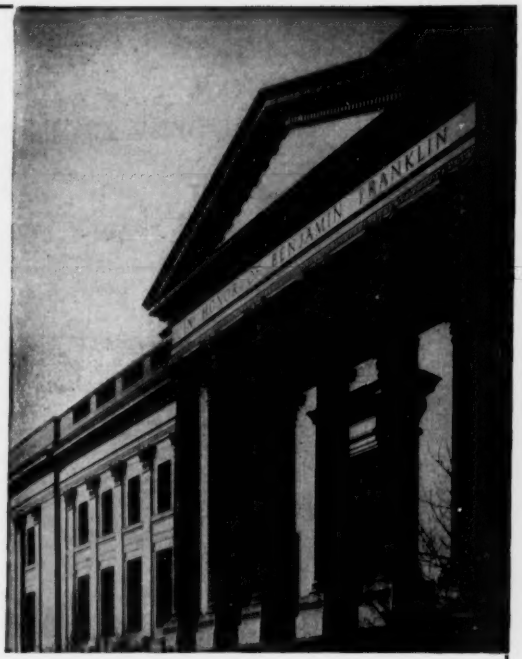

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